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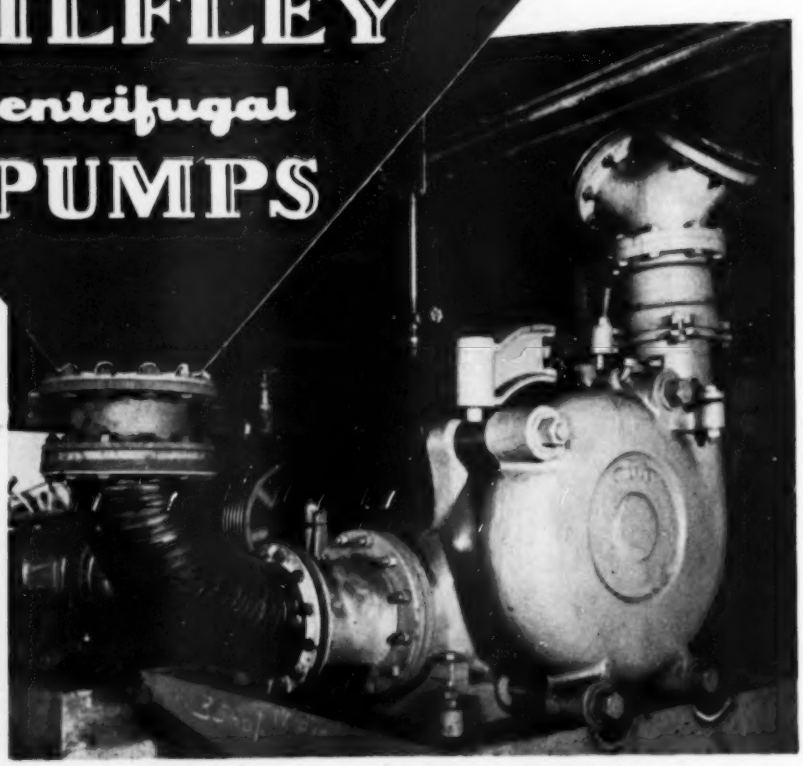

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# MINING engineering

VOL. 6 NO. 5 MAY 1954



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## COVER

**Yugoslavia, realizing that industrial expansion is dependent upon mineral industry development, is turning to increased exploration of its mineral resources. As the article on page 490 points out, the outlook is hopeful for many materials.**

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## —Personnel Service—

THE following employment items are made available to AIME members on a nonprofit basis by the Engineering Societies Personnel Service Inc., operating in cooperation with the Four Founder Societies. Local offices of the Personnel Service are at 8 W. 40th St., **New York 18**; 100 Farnsworth Ave., **Detroit**; 57 Post St., **San Francisco**; 84 E. Randolph St., **Chicago 1**. Applicants should address all mail to the proper key numbers in care of the New York office and include 6c in stamps for forwarding and returning application. The applicant agrees, if placed in a position by means of the Service, to pay the placement fee listed by the Service. AIME members may secure a weekly bulletin of positions available for $3.50 a quarter, $12 a year.

### MEN AVAILABLE

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**Geologist,** graduate, 31, family. Six years experience in mining and engineering geology. Supervisory status last 2½ years. Desires position U. S., West or Midwest. Now employed, 6 weeks notice preferred. M-71.

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**Coal Mine Executive Engineer or Manager,** registered engineer, age 53. Thirty years experience. Proven record in examination, layout, development, and operation of coal mine properties in Kentucky, Tennessee, and Alabama. Thorough experience and knowledge all phases of engineering requirements, latest methods of mechanical mining, safety programs, labor relations, and management. Capable taking complete charge. Currently employed; available reasonable notice. M-75.

**Mining Engineer,** 37, married. Fourteen years experience all phases underground mining operations, exploration, mine valuation and costs, and plant engineering. Registered professional engineer. Employed. Available reasonable notice. Will travel. M-76.

**Mining Geologist,** American, age 50, married. Twenty years experience southern Africa, thoroughly conversant with all branches, prospecting, exploration, and mine development, both gold and base metals. Available about August. M-77.

**Geologist-Petrographer,** M.S. degree in geology, and 2 years experience in petrographic work and 6 years experience in geophysics. Desires employment. M-79.

**Geologist-Engineer,** B.Sc., M.Sc., age 30, married, 3 children; 6 years experience in exploration-operational work in South America. Desires permanent responsible position in U.S. with little traveling in operating or administrative fields. Available immediately. M-80.

*(Continued on page 452)*

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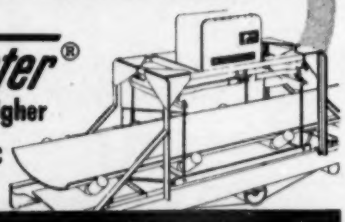

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## MEN AVAILABLE

*(Continued from page 450)*

**Mining Engineer and Instructor,** 27, single, B.S. in mining engineering. Experience: bituminous coal mining engineering, miner, top-slicing, zinc mine; college instructor in mining engineering. Interested in mine management and operations. Domestic or foreign. Will travel. M-78.

**Mining Engineer,** 25 years experience exploration, drilling, and operation of coal or lignite mines including construction mostly abroad. Reports on natural resources. Speaks several languages. Will travel. Available. M-81.

**Mining Engineer,** age 35, married, two children. Experience: mine superintendent, general mine foreman, and mine engineer, large and small underground operations. Also experienced in exploration work in Colorado Plateau region for uranium. Desires responsible position with aggressive mining company in U.S. or Canada. M-82.


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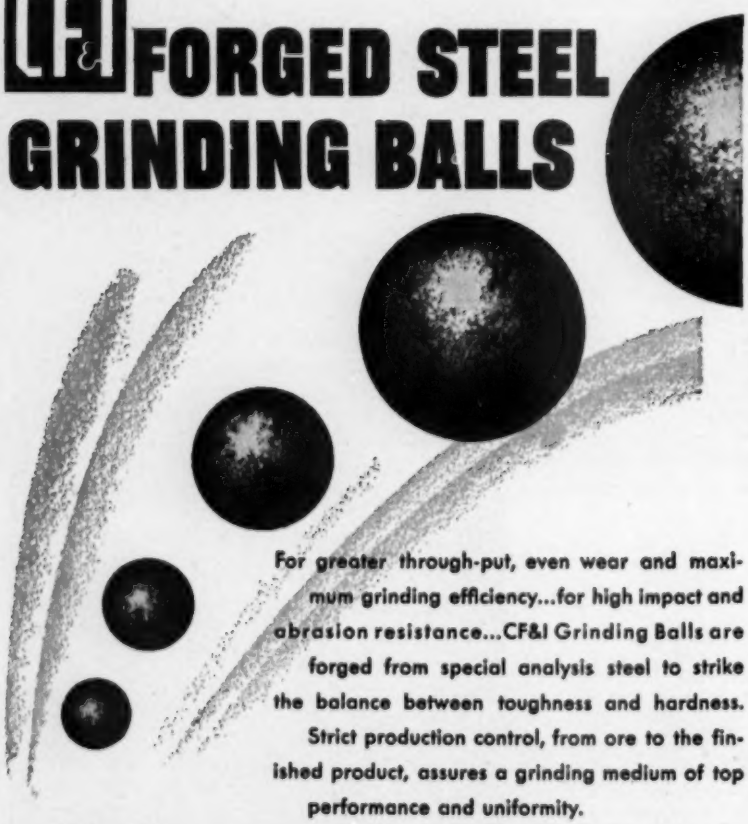

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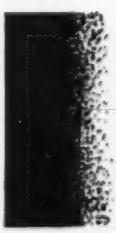

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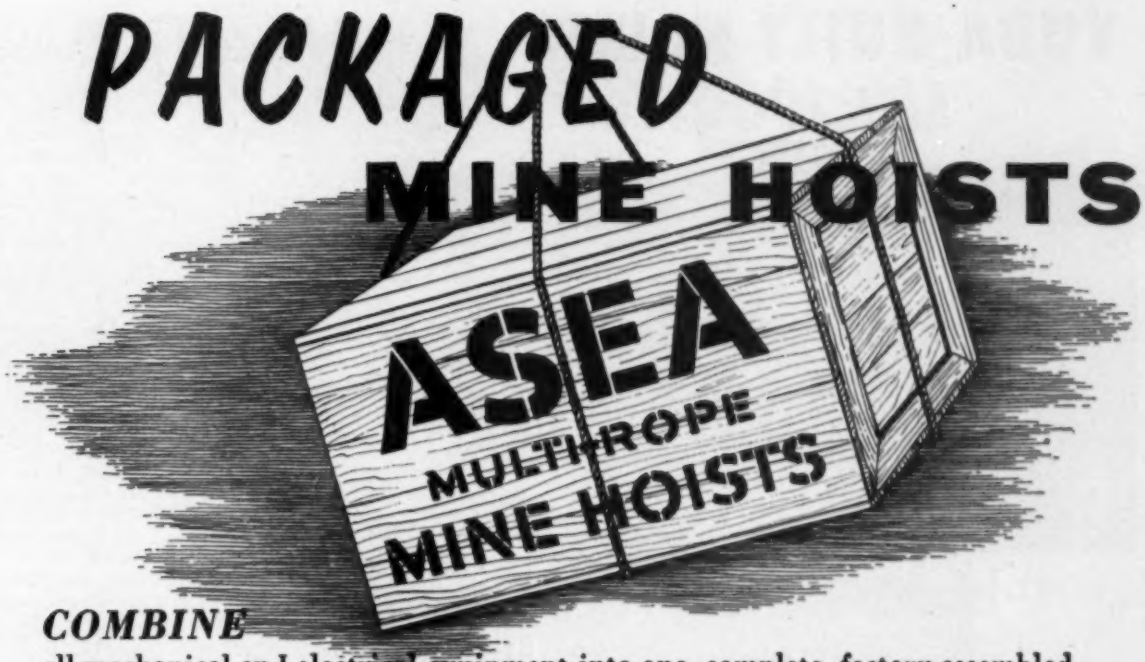


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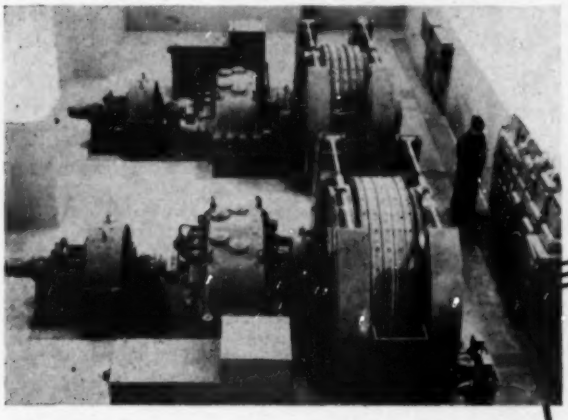

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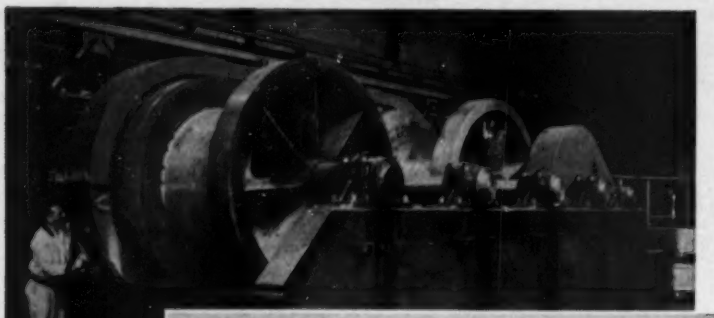

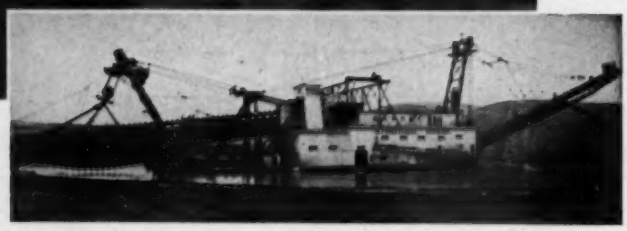

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65


# Meet The Authors

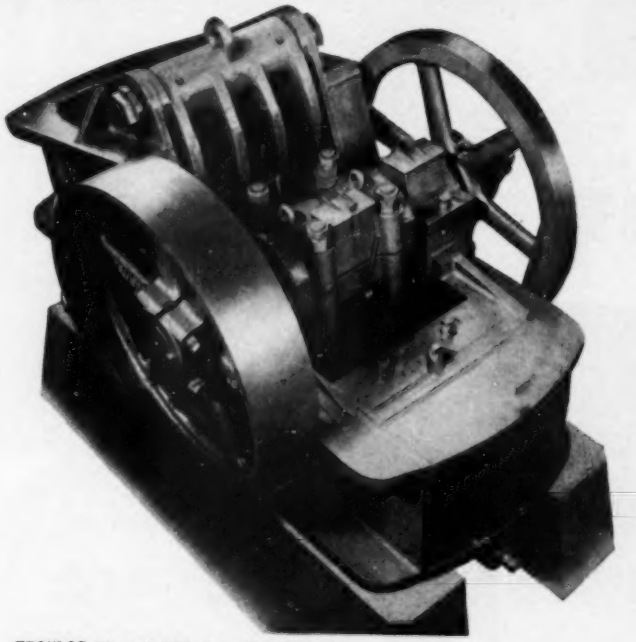
**Henry W. Hitzrot** (p. 534), special assistant for sales, The Dorr Co., Stamford, Conn., has been with the same firm since 1927, when he began his professional life. Born in McKeesport, Pa., he attended Phillips Exeter in New Hampshire, in preparation for Princeton. A track man during college days, he ran the quarter and half mile, and still recalls them as pretty tough distances. Mr. Hitzrot also belonged to Cap and Gown at Princeton. After graduation he attended Harvard, qualifying for an M.S. He has been manager of the Eastern Industrial Div. of Dorr, as well as member of the sales engineering and development staffs. A previous paper published by the AIME dealt with a fine grinding study on the Hollinger mine gold ore. Married and the father of four children, Mr. Hitzrot likes to find time for golf and gardening. Performance on the fairways depends on the day he plays and how he feels, Mr. Hitzrot reports.

**R. E. Powers** (p. 527), chemical engineer with the Freyn Dept., Koppers Co. Inc., Pittsburgh, is coauthor with E. H. Kinelski and H. A. Morrissey. A previous collaboration with Mr. Morrissey, *Quality of Iron Sinter as Related to Moisture and Coke Content*, was published by the *Journal of Metals*, April 1954. Mr. Powers is a former Fellow at the Mellon Institute and a graduate of Rensselaer Polytechnic Institute and New York University. **H. A. Morrissey**, Filtration Dept., H. H. Thoerner Co., will receive his M.S. in mathematics from the University of Pittsburgh at the June 1954 commencement. His hobby is gardening. **Mr. Kinelski** is a Fellow at the Mellon Institute.

**R. Schuhmann, Jr.** (p. 519), associate professor at Massachusetts Institute of Technology, is in this month's issue as a coauthor with P. L. de Bruyn, and J. Th. Overbeek. He has been the author of several papers in the past dealing with mineral dressing. Mr. Schuhmann was associated with the Manhattan District Project, AEC. In turn he attended Long Beach Polytechnic, California Institute of Technology, Missouri School of Mines, Montana School of Mines, and MIT. Hobbies include tennis and classical music. **P. L. de Bruyn** came to MIT from the University of Stellenbosch, South Africa. He is now an assistant professor at MIT. **J. Th. Overbeek** is a professor of physical chemistry at the University of Utrecht, Netherlands. During 1952 and 1953 he was a visiting professor at MIT.

MINING ENGINEERING is grateful to **Paul H. Brabant,** mining engineer, who recently returned from Yugoslavia, for two pictures used in the article, p. 490. Mr. Brabant helped check the article.

# Built for Endurance



**TRAYLOR** H and HB Jaw Crushers are made in 14 sizes. Feed openings from 8" x 12" to 56" x 72". Capacities from 4 to 640 tons per hour.

## Traylor Curved Jaw Plates outwear conventional types three to one

In scores of installations, the records show that Traylor Curved Jaw Plates outlast ordinary plates 3 to 1. For instance, records kept on a 36" x 48" crusher set at 4" to 5" show the average life of straight jaw plates to be 96,500 tons per set. Traylor curved Jaw Plates fitted to this crusher, and set at 3" to 3½", averaged 276,724 tons.

Here's why: Traylor Curved Jaw Plates apply power as a direct crushing force. The swing jaw plate exerts power directly counter to its opposing plate. This lessens lifting and churning of material to greatly reduce plate wear. As wear does gradually occur, it is evenly distributed so that Traylor plates retain their original curved shapes indefinately.

Although Traylor Jaw Crushers offer greater capacities . . . even at finer settings . . . they actually reduce power requirements. For the full story, clip the coupon and get our illustrated bulletin.

**TRAYLOR ENGINEERING & MFG., CO.**
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Send complete specifications and descriptions of Traylor H and HB Jaw Crushers immediately.

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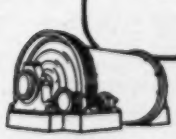
Primary Gyratory Crushers

Rotary Kilns

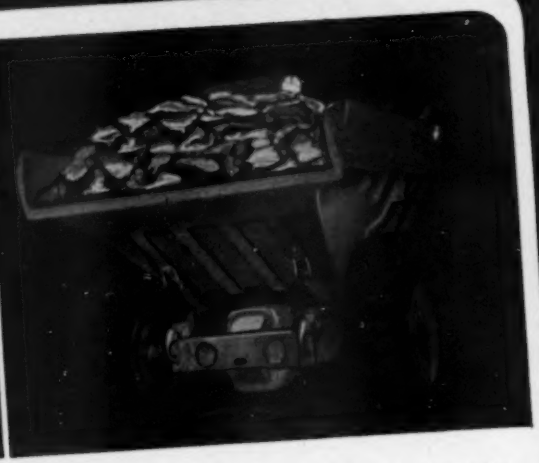
Secondary Gyratory Crushers


Ball Mills

Jaw Crushers

Apron Feeders

GM DIESEL
CASE HISTORY NO. 5310-1X



**OWNER:** American Zinc Company, North Friends Station Mine, Mascot, Tenn.

**INSTALLATION:** GM 4-71 Diesels powering 3 Koehring Dumptors. Units haul 8¼ tons of rock and ore on 1100-foot run up 11½% grade to surface.

**PERFORMANCE:** GM Diesel-powered units help 20-man crew produce 500 tons of ore per day. Use of rubber-tired equipment cut cost of access shaft construction by 70%.

GM
GENERAL MOTORS
DIESEL POWER

# GM DIESELS GO UNDERGROUND

## *to make trackless mining pay*

One of the world's most efficient small underground mines, the American Zinc Company's new North Friends Station mine is proving the economy of trackless operation. With a fleet of three GM Diesel-powered Koehring Dumptors handling the haulage, the mine is producing 500 tons of ore per day—about 25 tons of ore per man-shift. Mine Foreman Bill Armstrong says: "These units run along month after month with almost no repairs. Our costs are much less than we expected."

General Motors 2-cycle Diesels are just as much at home underground as on the surface. Two-cycle operation with uniflow blower scavenging gives more complete combustion of low-cost fuel for higher efficiency and cleaner exhaust. Used with exhaust scrubbers and adequate ventilation, mine air stays well within permissable limits. And two-cycle operation means faster acceleration, quicker response to controls, faster haul cycles for increased production.

There's a GM Diesel for every kind of mining job. Specify GM Diesel power in *your* equipment. It will save you money.

**DETROIT DIESEL ENGINE DIVISION**
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Single Units... 16 to 275 H.P. Multiple Units... Up to 840 H.P.

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**NEW CONVENIENCE!**
Naturally positioned controls . . . quickly and easily moved to either side.

**NEW SAFETY!**
Low center of gravity . . . high flange wheels . . . for greater stability on the rails.

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One-piece, large-capacity dipper . . . rounded bottom for self-cleaning.

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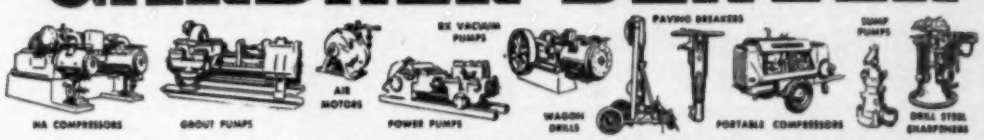
Only two points to check . . . both take the same commonly available oil.

**NEW FEATURES BY THE DOZEN!**
Write for details.

SINCE 1859

# GARDNER-DENVER

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**Gardner-Denver Company, Quincy, Illinois**

**In Canada: Gardner-Denver Company (Canada), Ltd., 14 Curity Avenue, Toronto 16, Ontario**

# Books for Engineers

**The Mechanics of Engineering Soils,** by P. Leonard Capper and W. Fisher Cassie, *McGraw-Hill Book Co. Inc.,* $6.50, 315 pp., 2nd ed., 1953.—Based on published literature and the author's experience, this book explains the basic principles of soil mechanics, describes the more usual tests, and introduces some of the practical applications. Several sections have been rewritten in the new edition.

**Geology of Lower Lake Quadrangle, Calif.,** by James C. Brice, *California Dept. of Natural Resources,* Bulletin 166, $2.50, 72 pp., 7 pl., 3 figs., 1953.—The Sulphur Bank mine, longtime quicksilver producer, and several smaller quicksilver properties are within the area studied which lies almost wholly in Lake County. The section on economic geology is written in part by J. Grant Goodwin.


## HARDINGE PLACES NEW TYPE "GYROTOR" AIR CLASSIFIER ON THE MARKET

Hardinge Company, Incorporated, announces a completely new type of dry classifier — the "Gyrotor" Air Classifier, for extremely close control of product in a dry grinding or separating operation. It can be used in closed circuit with a pulverizing mill or as a self-contained sizing unit for any moving stream of air-solids mixture.

The classifier is basically an inverted, truncated-cone shell with a motor-driven, bladed rotor of similar shape revolving on a vertical center axis inside the outer shell. The raw mixture of coarse and fine air-borne material is fed in from the bottom of the cone, passes upward in the annular space occupied by the whirling blades, describes a doughnut-shaped motion above the rotor, and discharges through a central opening in the top. Oversize not removed by the impact of the blades drops out in the eddy current above the rotor and centrifugal action deposits it on the outer shell of the classifier, where it slides to the oversize discharge at the base of the shell. The returning oversize is definitely cleaned of fines due to the winnowing action of the rotor blades in the annular space.

The classifier has a wide range of fineness control, and adjustment of product size is made simply by changing the rotor speed.

Hardinge Bulletin AH-449-2 describes this new classifier in detail.

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**National Electrical Code,** 1953 Edition (National Fire Codes, Vol. V), *National Fire Protection Assn.,* Boston, $3.00, 576 pp., 1953.—Replacing all previous editions and supplements, this defines basic minimum requirements for safety for electric conductors and equipment used for light, heat, radio, and other purposes. There are chapters on general applications; on installations involving special occupancies, equipment, etc.; and on construction specifications. A separate section gives electrical provisions of other NFPA standards.

**Proceedings of a Conference on the Utilization of Scientific and Professional Manpower,** *Columbia University Press,* $3.50, 197 pp., 1954.—During October 1953, 66 experts from all parts of the U. S. met for a 5-day conference, sponsored by the National Manpower Council, at Columbia University. The conference centered its attention on engineering, medicine, and teaching; the effective use of the personnel in each of them being of critical importance to the nation's health. The summary of the findings by Eli Ginzberg, director of research for the Council, develops six major approaches for solving problems of more effective manpower utilization.

**Atomic Energy in Industry, Second Annual Conference,** *National Industrial Conference Board,* $10.00, 264 pp., 1954.—This book is a transcript of the Second Annual Conference on Atomic Energy held Oct. 29 and 30, 1953 in New York. It contains the views of leading scientists and businessmen concerning the use of atomic energy for production of electric power. The book also highlights discussion on the use of radioisotopes in industry.

**Fresh Water from the Ocean,** for Cities, Industry, and Irrigation, by Cecil B. Ellis and members of the staff, Nuclear Development Associates Inc., *Ronald Press Co.,* $5.00, 217 pp., 1954.—An investigation of the possibilities of drawing fresh water from the ocean on the grand scale of 1,000 million gal per day. Various methods are assessed in terms of the major cost elements such as power construction and power requirements. Byproducts are briefly considered.

**Heating Ventilating Air Conditioning Guide 1954,** *American Society of Heating and Ventilating Engineers,* $10.00, 1128 pp., 32d ed., edge indexed.—Included are new data on methods of obtaining local relief in hot humid environments, new information on air and gas cleaning, new tables on steam requirements of process equipment, more detailed data on characteristics of pipe and tube. The manufacturers catalog data section contains 486 pages, illustrating the products of 319 manufacturers. Recent research has influenced changes, revisions, and additions to a large proportion of the chapters. Over 12 of the 52 chapters have been brought up to date with major changes. ASHVE two-color psychrometric chart, 24x32 in., in pocket.

## Please Order the Books Listed Below From the Publishers

**Draining from Bituminous Coal Mines,** by Kenneth L. Temple and W. A. Koehler, An Investigation Sponsored by Bituminous Coal Research Inc., Engineering Experiment Station Research Bulletin 25, *West Virginia University,* Morgantown, W. Va., free, illustrated, 37 pp. Also available from Bituminous Coal Research Inc., 2609 First National Bank Bldg., Pittsburgh 22, Pa.—Findings are presented on: the composition and properties of mine water; geological aspects of coal seams and associated strata in relation to acid formation; bacterial and chemical factors in the formation of acidity in mine water, and the outlook for prevention and control measures.

**The Relations of Hearing Loss to Noise Exposure,** *American Standards Assn.,* 70 East 45th St., New York 17, $1.50, 64 pp., 1954.—This report, directed toward the eventual development of standards and criteria for noise control, is the result of a year and a half of study by an exploratory committee of the ASA Sectional Committee on Acoustics, Vibration, and Mechanical Shock. Committee chairman, Prof. W. A. Rosenblith, Dept. of Electrical Engineering, MIT, states that management can now estimate the probable hearing loss of a group of individuals exposed to noise of specific characteristics for a given period of time.

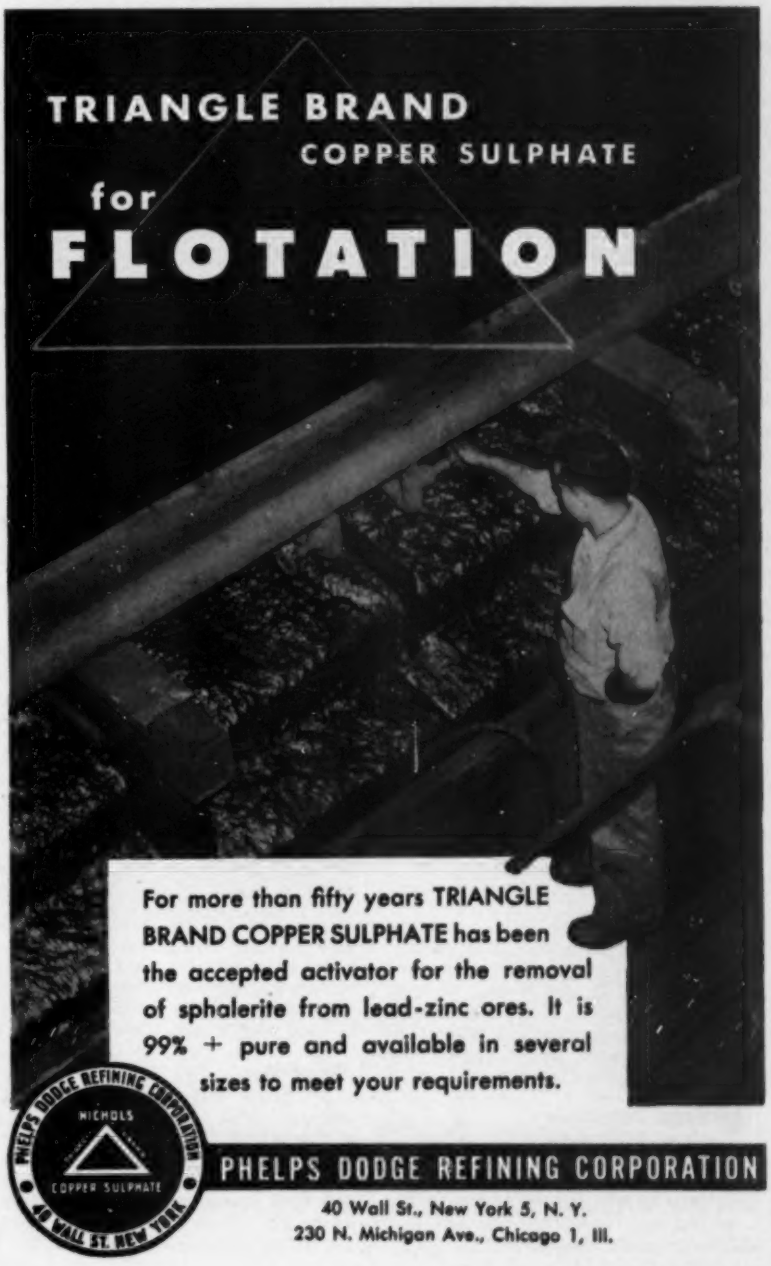
**Geology of the Galice Quadrangle, Oregon,** by Francis G. Wells and George W. Walker. This geologic quadrangle map is available for $1.00 from the Chief of Distribution, U. S. Geological Survey, Washington 25, D. C.

**Index to Publications, Colorado School of Mines 1953,** compiled and edited by *The Department of Publications,* Colorado School of Mines, Golden, Colo., free, 89 pp.—Covers publications from 1906 through 1953.

**Climate and Architecture,** by Jeffrey Ellis Aronin, *Reinhold Publishing Corp.,* $12.50, 304 pp., 1953.—A detailed analysis of the influence of climate on building design. The author reviews the physics of these influences, indicates their beneficial and disadvantageous aspects, and demonstrates how they may be effectively controlled. An extensive bibliography is provided.

**Geology of the Ortigalita Peak Quadrangle, Calif.,** by Louis I. Briggs, Jr., *California Dept. of Natural Resources,* Bulletin 167, $2.00, 61 pp., 4 pocket maps, 1953.—The area mapped lies on the west side of the San Joaquin Valley, largely within Merced County, although parts of it are in San Benito and Fresno Counties. Present in the area are magnesite, quicksilver, diatomite, gypsum, lime, sand, gravel, bentonite, and important oil field formations.

**Battery Chargers and Charging,** by Robert A. Harvey, *Iliffe & Sons Ltd.,* London, Approx. $5.50, 400 pp., 1953. —Construction and chemistry of all types of storage batteries. How fundamental principles of charging apply in specialized applications: electric locomotives, emergency lighting, and power systems, telephone exchanges, mines, ships, etc.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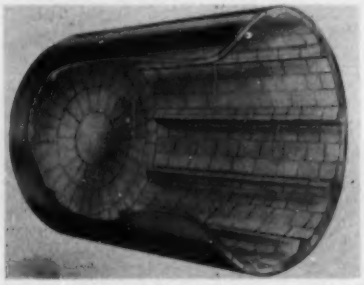
# Manufacturers News

New Products • *FILL OUT THE POSTCARD FOR MORE INFORMATION* • Equipment

### Mill Lining

*Coors Porcelain Co.* now makes ceramic mill lining of its high density material previously used only for grinding media. Coors' high density brick is claimed to substan-



tially outlast other types of ceramic lining now on the market. Double size shell brick, radial head brick, and integral cast lifter bars are among highlights of design for easier, cheaper installation. Specifications of the ceramic material list 20,000 psi tensile strength, 225,000 psi compressive strength, sp gr 3.4, and hardness of 9 (Mohs' scale). **Circle No. 1.**

### Loaders

Transo Div. of *Le Roi Co.* is now offering front end loaders in ½ to 1½ yd capacity that have torque converter, power steering, and reversing

planetary transmission as standard equipment. Features include bucket rocking action for fast loading, and travel speed up to 18 mph. Four-wheel drive provides maximum traction. **Circle No. 2.**

### Scintillation Counter

A portable scintillation counting survey meter from *R-C Scientific Instrument Co.* is applicable to extremely wide range of activity levels, having eight range settings from 0.05 mr/hr to 500 r/hr. Unit weighs 12½ lb with batteries. **Circle No. 3.**

### Methane Detection

*National Mine Service Co.* is exclusive U. S. distributor for the USBM-approved Riken methane indicator. Readings in less than a minute with a scale range to 6.0 are claimed for the instrument. **Circle No. 4.**

### Conveyor

A smaller vibrating conveyor featuring simplicity, reduced power consumption, and improved efficiency is now being offered by *Hewitt-Robins Inc.* Spring mounted pans are 4 in. deep, and 8, 12, or 18 in. wide. The single drive 1-hp model is available in lengths from 20 to 100 ft and prices range from $845 to $1725, depending on length and width of pans. **Circle No. 5.**

### Tough Dipper

Hopper type, all-cast rock dipper developed by *Electric Steel Foundry Co.* has integral tooth horns adapted to variety of tooth design, and the

front is designed with heavy sections at maximum wear points. A patented wedge door and latch has shock absorbing rubber between door and hinge. **Circle No. 6.**

### Blasting Machine

Maximum safety and reliability are aims of new portable blasting machine developed by Fidelity Instrument Corp. and *Atlas Powder Co.* and being distributed by Atlas. Machine uses high voltage dc gener-

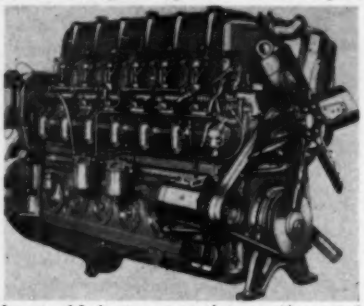
ator directly connected to discharge condenser. The portable unit is said to be weatherproof. The 450-v charge will handle 50 caps in parallel or up to 1200 single shot. **Circle No. 7.**

### Pulverizer

A vertical assembly laboratory pulverizer with horizontal grinding plates introduced by *Denver Equipment Co.* has all V-belt drive, eliminating gears. A ½-hp motor gives 900 rpm speed, and simple adjustment sets plates for samples to pass 80, 100 or 200 mesh. **Circle No. 8.**

### New Diesel Line

*Harnischfeger Corp.'s* P&H Diesel Engine Div., now has upped power output 36 pct in its line of 2-cycle diesels. Engines operate at 1800 rpm,



have 16:1 compression ratio, and 4.5x5.5-in. bore and stroke. Improved cylinder assemblies, better breathing, and improved cooling are among changes on the 2, 3, 4, and 6-cylinder models ranging from 58 to 255 hp output. **Circle No. 9.**

### Drill Bits

Full series of carbide-tipped, detachable bits recently added to *Copco Pacific* drilling equipment

line have already been proven in Sweden and Canada. Field tests in West are compiling data to verify claims indicating up to 300 pct more footage per bit. **Circle No. 10.**

### Dust Removal

A liquid precipitation stack gas scrubber for installation in low cost housings has been worked out by *Johnson-March Corp.* Six principles of dust collection are incorporated in system similar to that of earlier type V units, while the housings of concrete and cinder block construction are said to offer durability and trouble-free operation. **Circle No. 11.**

### Floor Trouble?

If floor clean up is the job, *Hild Floor Machine Co.* may have the answer in a heavy duty vacuum cleaner designed for industrial use. **Circle No. 12.** If floor surface itself is a headache, look into *Sauereisen Cements Co.'s* quick setting, acid-proof, pour-lay concrete, recommended for floors and other surfaces where corrosion is a problem. **Circle No. 13.**

# Free Literature

**(21) MATERIALS HANDLING:** "The Cost Cutter," nontechnical guide from *Automatic Transportation Co.* explains how special attachments give fork trucks extra versatility, explains which attachments are best for shifting, stacking, or storing. A flow chart form permits executives to put all elements of materials flow and handling problems in graphic terms.

**(22) SAFETY:** "What's New in Safety" is a bi-monthly folder from *E. D. Bullard Co.* condensing news about equipment and methods. Among other things, current issue discusses color for safety and a new safety brake compound.

**(23) INDUSTRIAL PRODUCTS:** *Johns-Manville* has a 40-page catalog that offers essential data on: insulations, refractory products, asbestos cement pipe, packings, gaskets, frictional materials, roofing, siding, flooring, partitions, ceilings.

**(24) RUBBER-LINED STEEL:** Transporting, storing, and handling acids or other corrosive materials? A bulletin from the Protective Coatings Div. of *Metalweld Inc.* shows how the abrasion resistant properties of a selected rubber stock can be combined with the strength of steel for economical and durable plates.

**(25) SEAMLESS METAL HOSE:** *DK Mfg. Co.'s* catalog No. 100 has data and specifications on Cobra seamless metal hose made from thin-wall tubing in stainless steel, bronze, monel, nickel, and steel. Made for high temperature, high pressure, and highly corrosive conditions, it is suited for such applications as suction and blower hose, conveyor hose, exhaust hose, shielding conduit, and as protective armor over corrugated metal hose.

**(26) STRIPPING & STOCKPILING:** Catalog No. 551 describes *Euclid's* Twin-Power scraper, already in use in construction projects, and now gaining acceptance in stripping and stockpiling operations. This scraper hauls loads of 18 cu yd struck, 21 cu yd at 3:1 slope and 24 cu yd at 1:1 slope, at speeds up to 31 mph and has the ability to self-load in most materials.

**(27) CONTROL VALVES:** Illustrated in the *A-P Controls Corp.* 4-page catalog are standard and custom-built flow control valves for starting,

stopping, mixing, blending, metering, measuring or controlling pressure, level, temperature, and expansion in refrigeration, heating, air conditioning or industrial applications. An individual "Problem Check" reply card is included.

**(28) "COMPETE OR COLLAPSE":** Booklet B-6133 on electrical modernization in industrial plants from *Westinghouse Electric Corp.* points out that while modernization is the key to successful competition, the first step in any modernization program must be the efficient distribution of electrical power.

**(29) POWER TRANSMISSION EQUIPMENT:** A 24-page catalog from *Lovejoy Flexible Coupling Co.* covers variable speed pulleys, wide V-belts, sheaves, motor bases, and Select-O-Speed transmissions.

**(30) CHEMICAL PUMPS:** *Roy E. Roth Co.* has a 24-page brochure dealing with special designs of regenerative turbine pumps available for acids, caustic solutions, solvents, and liquefied gases. Capacities are from 1 to 100 gpm.

**(31) ELECTROCHEMICAL REACTIONS:** *American Instrument Co.'s* Redox-O-Trol provides precise, automatic control of electrochemical reactions by controlling electrode potentials, and has sufficient output for preparing selective reduction and oxidation products in substantial quantities. It is also useful for electrolytic separation and determination of metals, and for precise control of chemical reactions.

**(32) EMERGENCY LIGHTING:** *The Electric Storage Battery Co.* has a 4-page pamphlet on Underwriters Laboratory approved auxiliary emergency lighting equipment. Featured are Exide Lightguard models M and T, which utilize a storage battery specifically designed for emergency lighting use.

**(33) EXCAVATOR:** A catalog from *Koehring Co.* shows the 15-ton lift, ½-cu yd dipper, 205 excavator, which can be equipped as a shovel, hoe, crane, or dragline. The unit is available either crawler mounted or on a truck body. Of interest to the contractor who wants to move his crane equipment from job to job is the 205 truck crane with a 32.6 mph max road speed.

**(34) SILENCERS:** *Burgess-Manning Co.* has two series of silencers for quieting air compressors, blowers, and vacuum pumps. The CA series is available in pipe sizes up to 6 in.; the LCA for sizes larger than 6 in.

**MAIL THIS CARD**

**for more information on items described in Manufacturers News and for bulletins and catalogs listed in the Free Literature section.**

**Mining Engineering** **29 West 39th St.** **New York 18, N. Y.**

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Please send me { More Information ☐ / Free Literature ☐ / Price Data ☐ } on items circled.

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| 61 | Students are requested to write direct to the manufacturer. | | | | | | | | |

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**(35) COMBUSTION CONTROL:** Bulletin R-10 from *The Hays Corp.* is an account of Morton Salt's "exposed" steam generator at Manistee, Mich., featuring air flow-steam flow compensated Hays combustion control. This semioutdoor boiler handles load swings up to 80,000 lb per hr at 85 pct efficiency.

**(36) FLAT TRANSMISSION BELTS:** Quaker Rubber Corp., Div. of *H. K. Porter Co. Inc.*, describes flat transmission belts by listing recommended uses, specifications, construction data, and sizes.

**(37) GYRATORY CRUSHERS:** "Superior Primary and Secondary Gyratory Crushers" from *Allis-Chalmers Mfg. Co.* shows how flexibility permits meeting a broad range of operating conditions. A

performance table, a selection of product curve, a formula for horsepower requirements, dimension tables are included as well as mention of A-C facilities for laboratory crushing tests. Interesting graph relates size of crusher feed opening to power shovel dipper capacities.

**(38) HEAT EXCHANGER:** *Niagara Blower Co.'s* bulletin No. 120 describes the operation of the Niagara Aero heat exchangers used in cooling or controlling of temperatures of industrial liquids. Operation of this equipment is shown by diagrams and examples of application by installation photographs.

**(39) WATER, SEWAGE, TRADE WASTE:** *Hardinge Co. Inc.* has a 6-page, color brochure on its line of water, sewage, and trade waste treating equipment. Numerous installations of Hardinge Circular Clarifiers are illustrated and various equipment applications are discussed. Bulletin AH-442 also has several typical flow sheets and a brief description of auxiliary apparatus such as digesters and flocculating units.

**(40) AC MOTOR CHART:** Confused by NEMA's change in ac motor frame assignment standards? *Reliance Electric & Engineering Co.'s* single page "Compar-A-Frame" quickly shows comparative dimensions of open and fan-cooled polyphase induction motors. There are subcharts for comparing frame sizes according to horsepower and speed, and a chart for comparison of dimension of old and new frames.

**(41) FINE CRUSHING:** The full story of the Gyradisc, termed a "finer" reduction machine by *Nordberg Mfg. Co.*, is in bulletin 228. Called a revolutionary method of comminution for producing large tonnages of fine product, the machine is result of several years of research and development based on Nordberg's long experience with such machines as the Symons cone crusher.

**(42) FORK TRUCKS:** *Elwell-Parker Electric Co.* has a folder on the model F-39T10 electric powered, 10,000-lb fork truck. Included are photographs, engineering drawings, design specifications, operating and construction features.

**(43) GAS MASKS:** *Acme Protection Equipment Co.'s* bulletin No. 541 illustrates and describes canister-type gas masks. Bulletin also deals with methods of determining gas concentrations, heating and humidity, and deficiency of oxygen; and presents data on recommended equipment for specific hazards in fire-fighting, industrial, and chemical fields.

**(44) SPLICING & REPAIR:** A 32-page, illustrated manual from *B. F. Goodrich* tells and shows the step-by-step procedure in the making of a BFG vulcanized splice in rubber conveyor and elevator belts. It describes the splicing materials involved, tools needed, and best conditions for splicing and repair.

**(45) DIESEL DATA:** Series of bulletins announced by Diesel Div. of *Harnischfeger Corp.* covers full line of P&H 20 to 138-hp engines, built in 2, 3, 4, and 6 cylinder models.

**(46) LIGHT PIPE:** As a practical help to users, *Naylor Pipe Co.* has issued a bulletin showing typical applications of lightweight lockseam spiralweld pipe and fittings in 4 to 30 in. diam.

**(47) TOP FEED FILTERS:** Described in bulletin 10-G from *Oliver United Filters Inc.*, the top feed filter is capable of reducing solids to bone dryness by utilizing hot air or suitable gas as the drying agent.

**(48) VIBRATORS:** *Cleveland Vibrator Co.* has a 4-page illustrated catalog on electric vibrators that handle any granular material—coal,

sand, gravel, cinders—in an almost noiseless operation. Units have heavy impact for their weight, and totally enclosed housing seals out moisture and dust.

**(49) FURNACES & OVENS:** *Minneapolis-Honeywell Regulator Co.'s* latest edition of "Furnace and Oven Controls" includes specifications and prices, on combustion safeguard equipment, valves, and accessories.

**(50) DERRICKS:** *Sasgen Derrick Co.* has a 16-page catalog of gas, electric, and hand-powered derricks, hoists, winches, elevating and hoisting equipment.

**(51) TWO-WAY RADIO:** "How to Modernize Your Materials Handling Operations" from *General Electric Co.* discusses the use of two-way radio in the materials handling field.

**(52) MILDEW PREVENTION:** A new and effective treatment for the prevention of bacteria damage is announced in a booklet from *F. C. Huyck & Sons.* Dewpruf is applied in the manufacturing process and is stated to be permanent and effective, eliminating the need for bacteriacides in mills to check mildew.

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THE EIMCO CORPORATION

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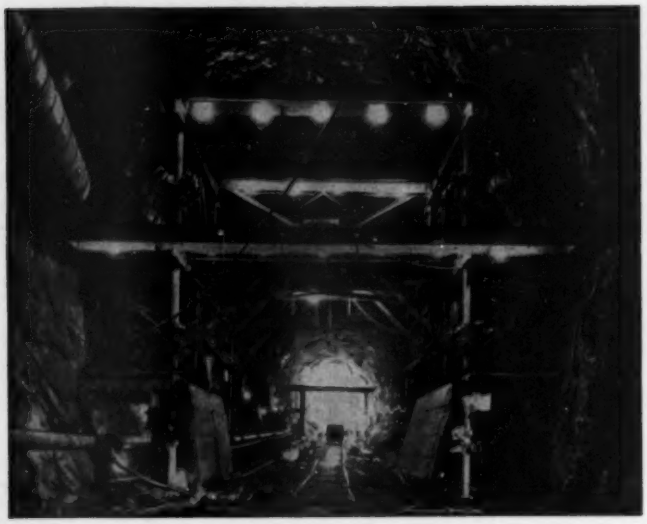
**Helped set new tunneling record** — Rock drills using I-R Carset Jackbits helped the contractor, Morrison-Knudsen, drive this 25'-diameter tunnel 10.1 miles in record time. Constructed for the Aluminum Company of Canada, it was pushed forward an average 47' per day during one 6 day week, thus exceeding the previous record for a bore of this size by about 7' per day. Water conveyed through it, from Lake Tahtsa, will provide the source for electrical power at Kemano to refine aluminum ore at the Alcan Aluminum Smelter at Kitimat, British Columbia, Canada.



# Nickel Alloy Steel Body of the Carset Jackbit

**Carset Jackbit** with carbide cutting edges set in 2% nickel alloy steel body. This specially developed steel, patented and produced by Crucible Steel Co. of America, Pittsburgh, Pa., is sold under the tradename "HY-Tuf." Low notch sensitivity and good notch impact properties at high hardness led to the selection of "HY-Tuf" by Ingersoll-Rand Co., New York, N. Y., producer of Carset Jackbits.

# *Retains Inserts under terrific Pounding*

## Resists Cracking and Deforming

Carbide cutting edges that readily cut through the hardest rock have helped Carset Jackbits set remarkable performance records.

But, no ordinary steel body can hold these carbide inserts securely. Nor can it resist deforming or cracking under the terrific pounding of heavy rock drills that strike 2,000 blows per minute.

To solve the problem, Ingersoll-Rand Company . . . producer of Carset Jackbits . . . fabricates the body from an alloyed steel containing 2% nickel. Combining great toughness and high strength, this unit exemplifies how desired combinations of strength, hardness, toughness, ductility and other useful properties can be developed together in a single nickel alloy steel composition . . . to improve the performance and economy of a product to meet a specific requirement.

From among the many standard nickel alloy steels available, you can select one which provides the best set of properties for meeting virtually any fabrication or service demand.

Whatever your industry, investigate how nickel alloy steels can improve your products or equipment. If you have a metal problem, send details for our suggestions. Write today.

**THE INTERNATIONAL NICKEL COMPANY, INC.** 67 WALL STREET NEW YORK 5, N. Y.

U. S. TUNGSTEN ORE production for 1953 reached 8,991,000 lb of contained tungsten, compared with 7,233,000 lb during the previous year. About one third of domestic production in 1953 was wolframite concentrate and two thirds scheelite concentrate. Tungsten Mining Corp.'s Hamme mine, in North Carolina, was the leading producer.

ROAN ANTELOPE COPPER MINES LTD. is planning to build an electrolytic copper refinery at Ndola, Northern Rhodesia, with initial annual capacity of between 55,000 to 60,000 LT. The plant will be built with financing of about $8.4 million. Roan is to set up a new firm, Ndola Copper Refineries Ltd., with all shares held by the parent company. Part of the money will be borrowed. Production is to begin in 1958.

**The U. S. contracted with the Chilean Government for 100,000 tons of copper at the market price. Since the end of the world copper shortage, Chile has been piling up a large surplus. The copper is destined for the U. S. strategic stockpile.**

COMMERCIAL PRODUCTION has started at Texas International Sulphur Co.'s processing plant near San Felipe, Baja California, Mexico, about 125 miles south of the U. S. border. The company claims to be the only plant on the North American continent producing crude commercial sulphur from surface ore. The sulphur is extracted by autoclave.

WHILE SHIPMENTS OF IRON ORE from Labrador to East Coast steel centers may start by August, Buffalo area steel mills probably won't reap benefits of the new deposits until next year. A spokesman for Republic Steel, one of the project's backers, said that facilities for handling shipments to Great Lakes ports won't be ready until 1955.

**Consolidated Mining & Smelting Co., Trail, B. C., announced that work will start immediately on a major expansion of the ammonia production facilities at its Alberta nitrogen dept., Calgary, Alberta.**

**New Mexico's metal miners were hard hit during 1953, with production down in every instance, according to a report by the University of New Mexico Bureau of Business Research. The state's most important metal, copper, suffered the smallest decline in output—8 pct. Hardest hit were lead and zinc, with lead down 60 pct and zinc down 73 pct.**

DEFENSE MINERALS EXPLORATION ADMINISTRATION added 19 minerals to the original list of 14 which may qualify for Government exploration. Bauxite, chromium, copper, fluorspar, graphite (crucible grade), lead, zinc, molybdenum, and cadmium exploration projects can qualify for Government participation covering 50 pct of the cost of the project. Antimony, asbestos (chrysotile only), beryl, cobalt, columbium, corundum, diamonds (industrial), kyanite (strategic), manganese, mercury, mica (strategic), monazite and rare earths, nickel, platinum group metals, quartz crystal (piezo-electric), rutile-brookite, talc (block steatite), tantalum, thorium, tin, tungsten, and uranium exploration projects can be Government financed on the basis of 75 pct.

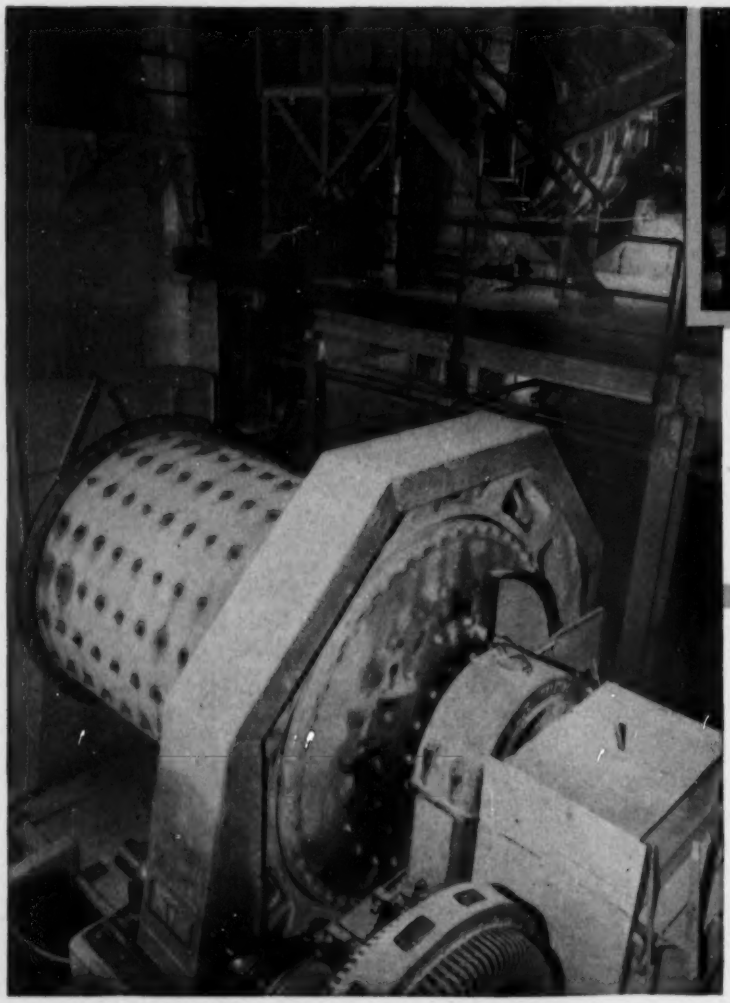
UTEX EXPLORATION CO. and Combined Metals Reduction Co. are awaiting AEC approval of a plan for the companies to join in construction of a $4 million uranium mill at Moab, in southeastern Utah. Charles A. Steen, Utex president, says the objective is to build a concentrator to serve independent operations in the Utah and Colorado uranium fields.

**Pan American Sulphur Co. plans to start sulphur production in October at a new plant at Jaltipan, Vera Cruz, Mexico. Large scale commercial sulphur shipments are expected in 1955. Capacity of the new plant, now under construction, is estimated at between 400,000 and 600,000 tons per year.**

THE BOLIVIAN GOVERNMENT, through its Ambassador to the U. S., has offered 10,000 to 12,000 tons of tin concentrate to keep the Texas City smelter in operation after the June 30 deadline set for its closing. Unless the smelter is sold to private interests it must be transferred to another Government agency when the RFC dies, according to the law. Some Government officials are not certain whether the law requires continued smelter operation or closure.

# Here's How
# INDUSTRY'S TOP TECHNICAL
# Helps Grinding Mill Operators

**HELPS PLANT AND CONSULTING ENGINEERS** — Here's the way it works. Let's suppose you are building a new concentrator and you want information and recommendations on crushing, grinding, screening, process flow and equipment needed. Allis-Chalmers specialists, familiar with the process problems involved, work with your engineers to provide a solution.



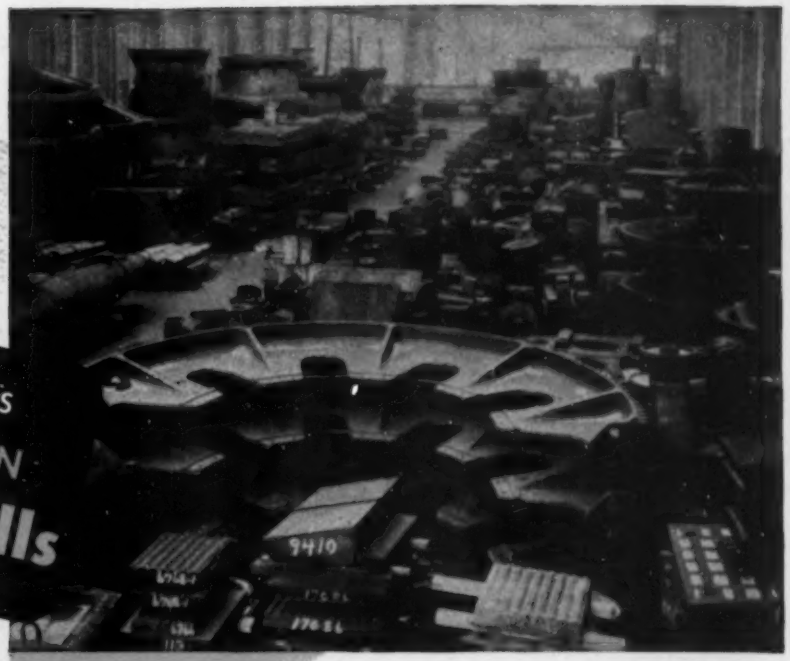
**TESTS ORE SAMPLES** — Ore samples are sent to the A-C laboratory for crushing, grinding, screening and additional tests to determine the equipment and process best suited to produce the desired end product. This laboratory is one of the best-equipped, best-staffed in the country. View of a section of the pilot grinding mill is shown.

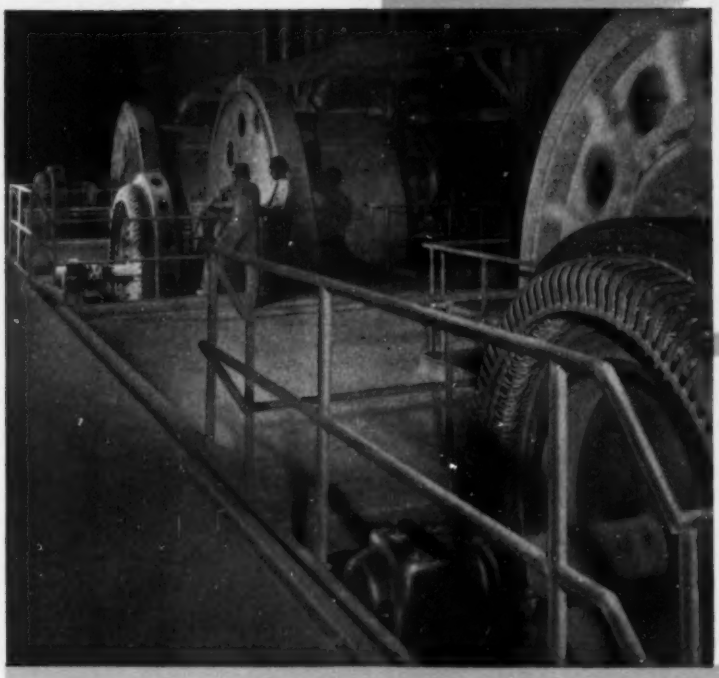
**FURNISHES INFORMATION ON PROCESS FLOW AND EQUIPMENT** — From lab test information and wide experience gained in solving similar problems, a flow sheet and a list of needed equipment are worked out. In the plant shown here, Allis-Chalmers recommended and furnished the rod and ball mills.

**ALLIS-**

# TEAM

ALLIS-CHALMERS
PROGRESS IN
**Grinding Mills**





**PROVIDES CONTINUOUS SERVICE**—When maintenance is necessary, a telephone call will put another A-C team to work on your problem. Complete records are kept on every Allis-Chalmers grinding mill. If parts are needed, these records are checked, and *exact* duplicate parts are speeded to you. Your nearest A-C District Office is always ready to help you. One section of the tremendous inventory of parts stocked at A-C is shown in this photo.

**A COMPLETE PLANT OR A SINGLE MACHINE**—Because Allis-Chalmers builds many types of equipment . . . crushers, grinding mills, screens, washers, kilns, coolers as well as the electrical power generating equipment, motors and controls, they can furnish a whole plant or a single machine. Allis-Chalmers offers the advantage of undivided responsibility for the complete process and equipment package.

**AN ALLIS-CHALMERS TECHNICAL TEAM** is always ready to work with your plant or consulting engineers on your grinding or processing problems. To take advantage of their services, call your nearest Allis-Chalmers District Office, or write Allis-Chalmers, Milwaukee 1, Wisconsin. A-4292

**ALLIS-CHALMERS EQUIPMENT FOR THE MINING AND ROCK PRODUCT INDUSTRIES**

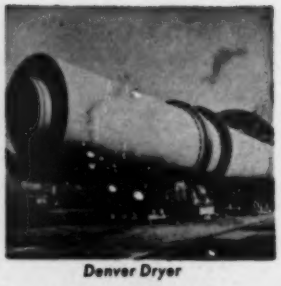
Crushers, all types—
Vibrating screens, all types
—Kilns—Coolers
—Washers—Dryers
—Smelting equipment

# CHALMERS

A-C ALLIS-CHALMERS

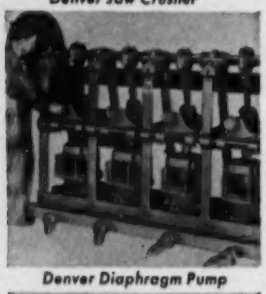
Denver Jaw Crusher

Denver Ball Mill



Denver Dryer

Denver Disc Filter



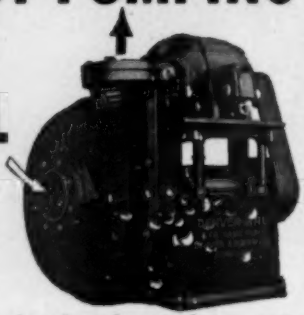
Denver Diaphragm Pump

# LOWER COST PUMPING

**is possible with**

# DENVER SRL

***RUBBER LINED PUMP***



## HERE'S WHY...

Power cost is substantially less than for other sand pumps on similar service. REASON: greater hydraulic efficiency resulting from simple design, rubber parts and lighter weight.
Accuracy of rubber parts results in 1½ to 3 times greater efficiency than other sand pumps.

## LEARN MORE ABOUT ACTUAL SAVINGS

If you pump —⅛" abrasive material, describe your pumping requirements. Let us study and report specific advantages of Denver SRL Pumps over pumps you now use. Ask today for bulletin P9-B8.

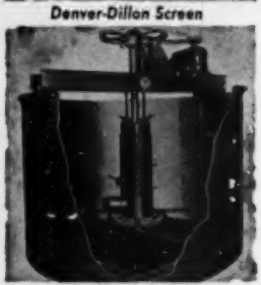
**Also Available in "Acid Proof" Construction.**

***EXAMPLES OF DENVER SRL RUBBER LINED PUMP CURVES****

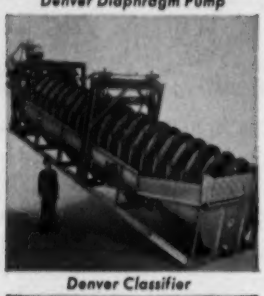
| Size | Gals. Water Per Minute | | 20' head | 40' head | 60' head | 80' head | 100' head |
|---|---|---|---|---|---|---|---|
| 2"x 2" SRL | 50 | RPM | 838 | 1090 | 1320 | 1525 | |
| | | HP | .60 | 1.5 | 2.3 | 3.2 | |
| 3"x 3" SRL | 100 | RPM | 760 | 1053 | 1303 | 1453 | |
| | | HP | 1.1 | 1.9 | 3.4 | 4.3 | |
| 5"x 5" SRL | 300 | RPM | 590 | 800 | 956 | 1087 | |
| | | HP | 2.4 | 5.1 | 8.3 | 11.5 | |
| 6"x 6" SRL | 1000 | RPM | | 862 | 1005 | 1122 | |
| | | HP | | 14.4 | 22.6 | 30.0 | |
| 3"x 3" SRL-C | 150 | RPM | 870 | 1145 | 1385 | 1580 | 1745 |
| | | HP | 1.5 | 3.2 | 5.3 | 7.2 | 9.6 |
| 5"x 4" SRL-C | 350 | RPM | 655 | 850 | 1020 | 1160 | 1280 |
| | | HP | 2.9 | 5.4 | 8.3 | 11.4 | 14.5 |
| 8"x 6" SRL-C | 800 | RPM | 500 | 655 | 780 | 890 | 980 |
| | | HP | 5.7 | 11.6 | 16.8 | 22.3 | 28.6 |
| 10"x 8" SRL-C | 2000 | RPM | 485 | 610 | 710 | 800 | 855 |
| | | HP | 14.0 | 27.8 | 41.2 | 56.3 | 71.6 |

*(*Multiply these horsepower ratings by the specific gravity of your pulp to determine actual brake horsepower required.)*

Denver-Dillon Screen

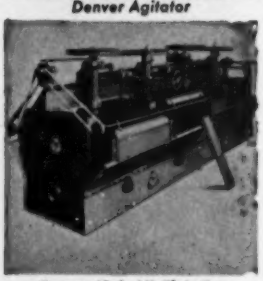


Denver Agitator

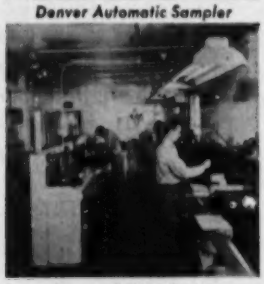


Denver Classifier

Denver Automatic Sampler



Denver 'Sub-A" Flotation



Denver Testing Service

Denver Hydroclassifier

*"The firm that makes its friends happier, healthier and wealthier"*

DECO FLOTATION ENGINEERS — DENVER EQUIPMENT 24 HOUR SERVICE COMPANY

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***Offices also in El Paso, Vancouver, Mexico. D.F., London, Johannesburg***

# PUERTO ORDAZ CONVEYOR GOING STRONG

Ore is piling up at Puerto Ordaz, Venezuela, from mining operations at Cerro Bolivar. The 400-ft span, self-propelled belt conveyor bridge travels longitudinally over the pile and a belt conveyor tripper travels across the bridge, discharging ore at any point. Feeders at lower right (photo on left) operate in tunnels under pile. Ship is loaded at dock on the right. Prime contractor for the ore handling system was Link-Belt.

## Coal Pipeline Plan Nears Final Stages

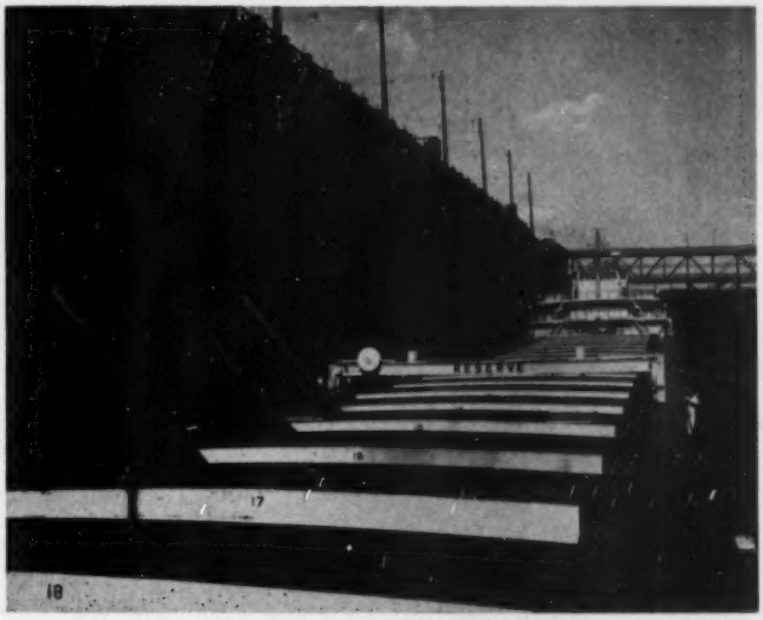
Plans are almost complete for a 110-mile long coal pipeline to run from mines near Cadiz, Ohio, to Cleveland Electric Illuminating Co.'s plant at Eastlake, near Cleveland.

The line will be owned by Pittsburgh Consolidation Coal Co., world's largest producer of bituminous coal. Cleveland Electric is planning to spend more than $2 million on the Eastlake terminus. Elmer L. Lindseth, utility company president, commented that "through lower cost coal, we can attract new industries." Raymond P. Snow, director of purchasing for Cleveland Electric, noted that the pipeline is expected to save about $1.25 per ton from present rail freight rates. Savings will be shared by the coal company and the utility.

Pittsburgh Consolidation, while confirming that planning is in the final stages, did not give an initial operating date. Total cost of the line also has not been announced.

Crushed coal, ⅛ in. diam, will be slurried with water, and pumped through the pipeline at high pressure. Pittsburgh Consolidation has been experimenting with a coal pipeline for some time and has successfully operated a 10-mile unit in Ohio. (See MINING ENGINEERING *Trends*, p. 472, May 1953.)

## LAKE SEASON OPENS




The first large ore boat in history to carry a full load of nothing but taconite pellets sailed out of Two Harbors, Minn., for Toledo April 19. The sailing of the ore ship, the *Reserve*, also inaugurated the Great Lakes ore shipping season. Mined and processed at Babbitt, Minn., by Reserve Mining Co., the pellets were stockpiled during the winter. Republic Steel Corp. and Armco Steel Corp. are joint owners of the Reserve Mining operation.

***LOOK what they're saying about***

# ANACONDA SECURITYFLEX* SHOVEL CABLE

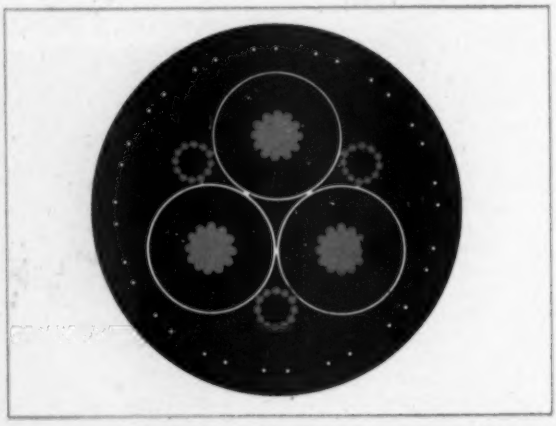
**GENERAL MANAGER:**
"This cable saves us money . . . there are far fewer breaks . . . and far fewer shorts from ground wires."

**MINE ENGINEER:**
"No matter how we run it over rocks, it holds up well. It must be the jacket. It wears like iron."

**MINE FOREMAN:**
"Securityflex sure is flexible . . . mighty easy to handle, too . . . the toughest cable we've ever used."

**MINE SUPERINTENDENT:**
"Our men can splice Securityflex easily and in less time. That saves us on down-time."

These are the things Anaconda salesmen hear daily about Securityflex Type SH-D Shovel Cable. Why not see *your* Anaconda Sales Office or Distributor for full information about this cable? *Anaconda Wire & Cable Co., 25 Broadway, New York 4, N. Y.* *Trade Mark 54388



**AND THE REASON USERS CAN SAY THIS IS BECAUSE:**

- **New BUTYL INSULATION provides better resistance to heat, moisture and damage by compression**
- **New NEOPRENE JACKET is tougher and more abrasion resistant**
- **RUBBER CORES cushion the ground wires . . . help prevent broken wires**
- **New COPPER-COTTON SHIELD is easier to splice**

***the right cable for the job***

**ANACONDA®**

**WIRE AND CABLE**

# Surging Canadian Mineral Output Climbs To New High

## Canadian Mineral Production — 1953

| Commodity | Unit | 1952 Quantity | 1952 Value $ | 1953 (Estimated) Quantity | 1953 (Estimated) Value $ |
|---|---|---|---|---|---|
| Metallics— | | | | | |
| Antimony | lb | 2,330,900 | 601,483 | 1,530,000 | 344,290 |
| Bismuth | lb | 162,373 | 347,224 | 98,821 | 197,308 |
| Cadmium | lb | 948,587 | 2,086,891 | 1,315,989 | 2,631,978 |
| Cobalt | lb | 1,421,923 | 3,226,903 | 1,754,324 | 3,772,880 |
| Copper | lb | 516,075,097 | 146,679,040 | 503,224,887 | 150,631,485 |
| Gold | fine oz | 4,471,725 | 153,246,016 | 4,061,205 | 139,826,286 |
| Indium | fine oz | 404 | 909 | 6,000 | 13,500 |
| Iron ore | ton | 5,271,849 | 33,744,311 | 6,501,060 | 42,722,000 |
| Iron ingots | ton | 32,422 | 1,815,007 | 97,682 | 3,776,000 |
| Lead | lb | 337,683,891 | 54,671,021 | 394,458,042 | 51,969,847 |
| Magnesium and calcium | | — | 4,812,368 | — | 4,607,633 |
| Molybdenite ($MoS_2$) | lb | 505,964 | 409,831 | 152,521 | 114,390 |
| Nickel | lb | 281,117,072 | 151,349,438 | 287,931,430 | 160,861,368 |
| Palladium, etc. | fine oz | 157,407 | 7,559,109 | 161,550 | 7,396,897 |
| Platinum | fine oz | 122,317 | 10,916,792 | 134,108 | 12,237,355 |
| Selenium | lb | 242,030 | 786,599 | 356,500 | 1,312,600 |
| Silver | fine oz | 25,222,227 | 21,065,603 | 30,145,259 | 25,334,503 |
| Tellurium | lb | 6,035 | 10,259 | 16,430 | 28,758 |
| Tin | lb | 212,113 | 253,581 | 656,000 | 656,000 |
| Titanium ore | ton | 51 | 459 | 4,658 | 27,566 |
| Tungsten ($WO_3$) | lb | 1,493,111 | 4,488,237 | 2,384,554 | 5,051,508 |
| Zinc | lb | 743,604,155 | 129,833,285 | 797,647,860 | 95,398,683 |
| Total, Metallics | | | 727,904,366 | | 708,912,835 |
| Fuels— | | | | | |
| Coal | ton | 17,579,002 | 111,026,149 | 15,760,000 | 102,100,000 |
| Natural gas | M cu ft | 88,686,465 | 9,517,638 | 99,628,189 | 11,023,350 |
| Peat | ton | 32 | 320 | 30 | 300 |
| Petroleum, crude | bbl | 61,237,322 | 143,038,212 | 81,311,531 | 198,111,542 |
| Total, Fuels | | | 263,582,319 | | 311,235,192 |
| Nonmetallics— | | | | | |
| Arsenious oxide | lb | 1,708,351 | 76,876 | 1,424,250 | 78,333 |
| Asbestos | ton | 929,339 | 89,254,913 | 911,713 | 87,633,124 |
| Barite | ton | 136,002 | 1,521,162 | 248,973 | 2,316,474 |
| Diatomite | ton | 28 | 1,074 | 3 | 150 |
| Feldspar | ton | 20,267 | 330,635 | 20,564 | 337,716 |
| Fluorspar | ton | 82,187 | 2,523,408 | 90,078 | 2,657,104 |
| Graphite | ton | 2,040 | 255,732 | 3,476 | 361,184 |
| Grindstones | ton | 42 | 5,720 | 15 | 900 |
| Gypsum | ton | 3,590,783 | 6,538,074 | 3,765,763 | 7,487,928 |
| Iron oxides | ton | 11,487 | 194,922 | 9,297 | 172,037 |
| Magnesitic-dolomite and brucite | | — | 2,715,266 | — | 3,122,122 |
| Mica | lb | 2,014,941 | 194,106 | 1,856,713 | 171,372 |
| Mineral waters | gal | 311,495 | 166,033 | 312,400 | 166,450 |
| Nepheline syenite | ton | 82,681 | 1,111,950 | 108,000 | 1,402,000 |
| Phosphate rock | ton | — | — | 1,100 | 10,000 |
| Peat moss | ton | 74,899 | 2,443,765 | 84,847 | 2,497,219 |
| Quartz | ton | 1,783,081 | 2,253,500 | 1,651,791 | 1,608,195 |
| Salt | ton | 971,903 | 7,774,815 | 946,650 | 7,356,595 |
| Silica brick | M | 3,544 | 606,394 | 4,155 | 735,695 |
| Soapstone and talc | ton | 23,032 | 280,612 | 26,863 | 294,250 |
| Sodium sulphate | ton | 122,590 | 1,708,807 | 112,881 | 1,704,313 |
| Sulphur | ton | 423,788 | 3,851,183 | 333,873 | 3,127,464 |
| Titanium dioxide | ton | 30,805 | 1,238,103 | 98,660 | 4,217,000 |
| Total Nonmetallics | | | 125,047,050 | | 127,457,625 |
| Total, Clay Products and Other Structural Materials | | | 168,808,618 | | 183,605,851 |
| TOTAL* | | | 1,285,342,353 | | 1,331,211,503 |

* The above figures do not include data for pitchblende products.

It doesn't look it here, but this is the Knob Lake terminus of a 350-mile railroad which will carry Canadian iron ore to the St. Lawrence River port of Seven Islands, P. Q. Clearing operation is finished and railroad is almost ready.

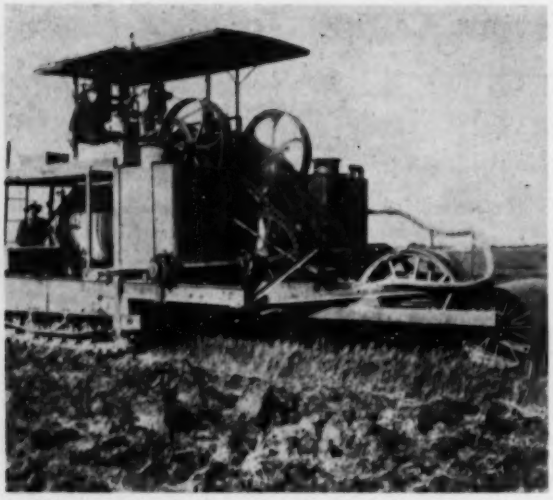
Canada's mineral production in 1953 totaled $1.33 billion according to preliminary estimates by the Dominion Bureau of Statistics. It was a new high for the country and $46 million more than the 1952 total of $1.29 billion. Petroleum made the greatest gain, with a value of $55 million more than in 1952.

Cement climbed $12 million and iron ore jumped $9 million, while zinc dived $34 million. Gold also slid approximately $13 million, while coal dropped $9 million. The total value of metals declined, with the 1953 estimate at $709 million, compared with $728 million in 1952.

Some of Canada's gold mines were hit by long strikes which curtailed production during the last half of the year. Production was 4.1 million fine oz valued at $140 million. The 1952 production was 4.47 million fine oz worth $153 million.

Lead and zinc tonnages increased but declining prices resulted in lower return, $52 million and $95 million respectively. Iron ore shipments at 6.5 million tons established another record for the year, while the greatest value for any metal was set by nickel at $161 million. Mineral fuels value increased 18 pct over 1952, hitting $311 million. This is the first time in almost 25 years that gold has been moved out of first place in the dollar value race. Petroleum topped the minerals field with 81 million bbl at $198 million.

With several Canadian coal mines halting production, output was down almost 2 million tons at 15.7 million tons. New highs were established for structural materials at $183 million.



Power steering is not as young as it looks. This first practical track-type tractor, built by Benjamin Holt and tested in 1904, boasted it as standard equipment. The machine was a converted standard steam traction engine.

Getting ore to market in 1922 meant overland haulage via tractor. This Best Sixty was owned by the West End Chemical Co., Las Vegas, Nev. At one time tractors were used extensively for freight transport in the West.

# 1954 — Fifty Years on Tracks for U. S. Industry

Fifty years ago the Holt Mfg. Co. tested the first successful crawler tractor near Stockton, Calif. A new era was born. Today, in the U. S. alone, some 340,000 crawler tractors are used in mining, logging, farming, road building, and other fields. The figure is exclusive of military employment of tracked vehicles.

The crawler was born because of a need for a compact machine that would ride high on the soft delta lands of California. Benjamin Holt, president of Holt Mfg. Co., and Daniel Best, president of Best Mfg. Co., had been making steam traction engines since 1890. To lick the soft soil problem, they used larger and larger wheels, adding to the bearing surface of the machines.

One Holt unit had three 6-ft wide wheels on either side. The wheels stood 7½ ft high and the overall width of machine was almost 46 ft. Weight of these Goliaths ranged up to 40 tons. They provided the necessary power, but were almost impossible to transport, and handled awkwardly.

One of the most interesting features of the first crawler tractor was its power steering and separately controlled steering clutches.

In 1906 Holt was the first to put a gasoline engine in a crawler and in 1913 scored another first with an all-track model or "muley" which eliminated the tiller wheel in the front.

In 1908 Holt bought out the Best Mfg. Co., but in 1910 C. L. Best, son of Daniel, organized the C. L. Best Gas Traction Co., Elmhurst, Calif. Young Best manufactured wheel-type, gasoline driven tractors at first, but in 1913 came out with his first track-type tractor, the Best 75-hp Tracklayer. Competition between the two rival companies was keen until a merger was effected in 1925. It resulted in the Caterpillar Tractor Co., at Peoria, Ill., still the center of "Cat" activity.

While the first crawlers were destined for farm work, they were soon

A Caterpillar Thirty tractor equipped with a bulldozer blade cleans up floor of a strip mining operation in 1931. The end of World War I saw tractors gain in importance in industries other than agriculture.

It wasn't too long before tractors found their way underground. Here, Athey Truss side-dump trailers remove material in an underground mine near Kansas City, Mo., in 1930. Much auxiliary tractor equipment began to develop.

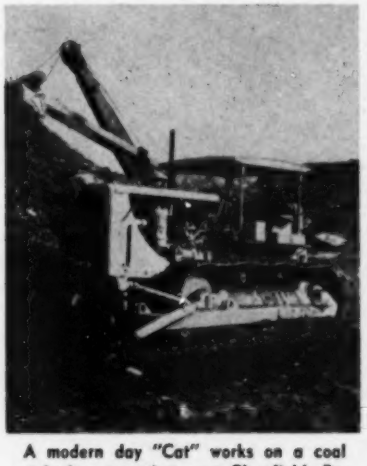
Combination "Cat" tractor and track-equipped wagon haul overburden from a strip mining operation in 1933.

employed in other fields. Crawlers hauled overland freight for a time, but the tractor's roadbuilding ability almost proved its undoing. As crawlers built roads, crawler-drawn overland freight gradually retreated out of existence.

World War I saw the first tank based on crawler design. Crawlers also hauled artillery, supplies, and personnel on the battlefields of two continents. After the war, the crawler spelled the end of the horse as the number one earthmover. Multiple steel-wheeled wagons and scrapers came into being. Holt was also the first to use heat-treated alloy iron tractor parts in 1918. In 1931 diesel powered tractors were introduced.

World War II crawlers operated in every theatre of action. They helped build landing strips, fill shell holes, destroy pillboxes, clear debris and jungles, and construct roads.

More recently crawlers are coming into a wide variety of uses in both underground and open pit mines. To commemorate the 50 years of industrial history, Caterpillar is conducting a program throughout 1954 based on the theme *50 Years on Tracks.*



A modern day "Cat" works on a coal stripping operation near Clearfield, Pa. Equipment is a No. 8A bulldozer. Fiftieth anniversary of first successful track-equipped unit is being celebrated this year.


**Anywhere**—in harbors or undeveloped areas—in faster time with sizable savings in money!

*Completed structure August 28, 1952, six months after contract was signed.*

This is the story of the

**De LONG DOCK**

**APRIL 18, 1952.**
First dock section, 82' by 377' ready for launching.
Dock sections were economically fabricated at an Orange, Texas shipyard and launched for towing to dock site.

Prefabricated to required size and strength at shipyard.

**MAY 21, 1952.**
First dock section, arriving at site on Orinoco River, after being towed across 3,000 miles of ocean.

First section loaded with its own caissons and all erection gear and equipment required for project.

**MAY 22, 1952.**
Crane placing 6 ft. diam., 100 ft. long steel caissons in wells fitted with Airjacks. Crane, Airjacks and other equipment were later transferred to second and third sections for erection purposes. Elevation of dock can be regulated to 1/32 of an inch.

After caissons are placed, De Long Airjacks working simultaneously, raise dock section to desired elevation.

A week after arrival at Orinoco Mining Company's site on the Orinoco River, Venezuela, first dock section berths ship, and unloading of cargo begins. Two additional units make this pier 1,130 ft. long, 82 ft. wide, and 15 ft. deep, shown above.

No special foundation preparation; no cofferdams. High tides, swift water no obstacle. De Long Docks can be erected under any field conditions.

*Write today for illustrated booklet which describes the advantages offered only by the De Long Dock.*

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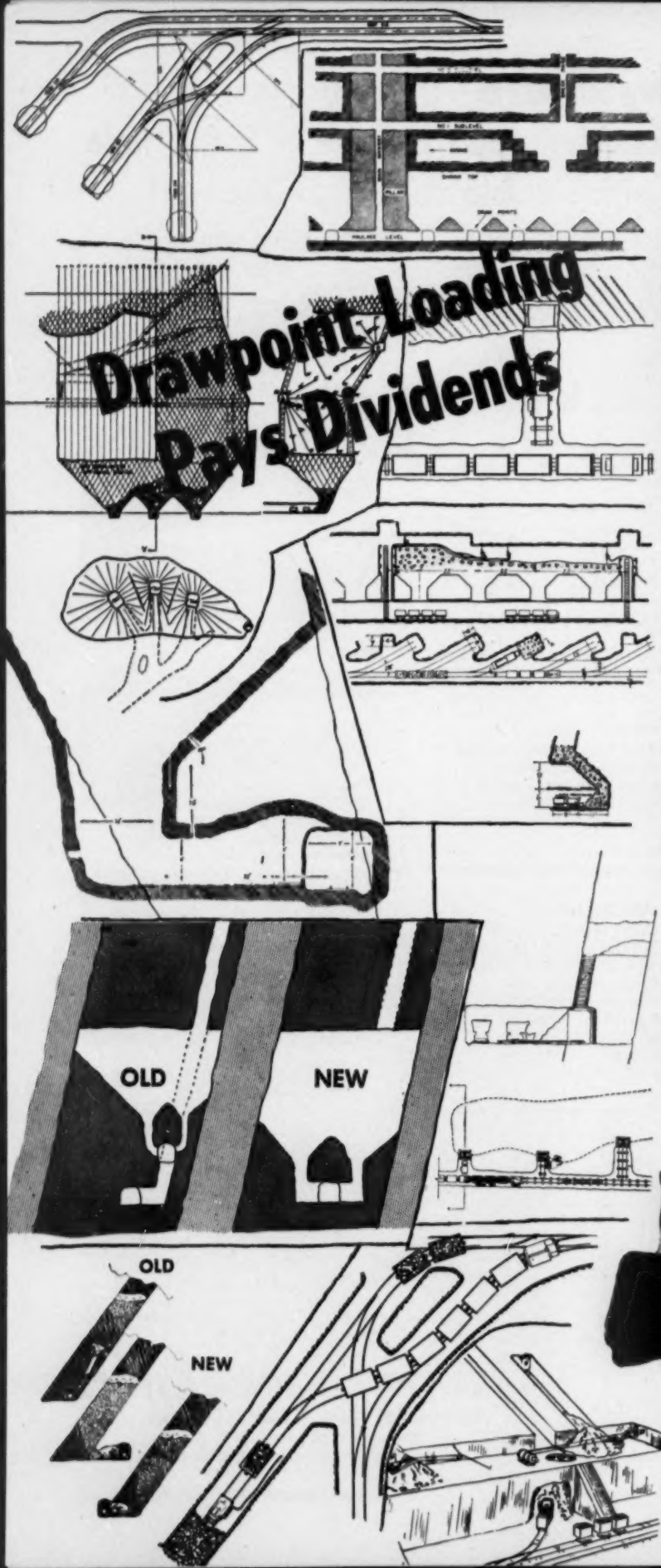



Numerous advantages of production loading from drawpoints with mechanical loaders make this system of mining attractive to men faced with marginal ores, low metal prices and rising costs.

These are some of the advantages:

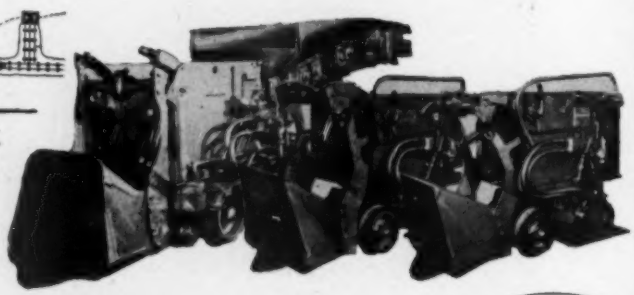
1. **INCREASED OUTPUT PER MAN SHIFT.** Substantially greater production can be realized by simply putting an Eimco loader in production loading. Some mines have gone to greater mechanization by using one man as loader and locomotive operator with an increase to 18-20 tons per man shift.

2. **INCREASED SAFETY FOR THE MAN UNDERGROUND.** Drawhole mining with mechanical loaders eliminates the chute and grizzlie system with its inherent hang-ups, secondary blasting, chute repairs and hazardous initial development program.

3. **LOWER COST.** Time wasted in developing a fancy system of chutes, grizzly chambers, manways and the expense of building chutes is eliminated. The expense of maintaining chutes and extra expense of secondary blasting at grizzly level are not necessary.

4. **GREATER EFFICIENCY.** Loading cars full without spillage and loading maximum size material into cars is standard practice with mechanical loaders. Equipment used in one drawpoint can be easily moved to another drawpoint. When the area is mined out 100% salvage value on equipment can be realized with mechanical loaders where no salvage value is realized on timber in chutes.

For best results in dependable equipment for drawhole loading use an Eimco loader. There is an Eimco for every loading job — one that will fit your production requirements and your haulage equipment. For more information write The Eimco Corporation, P. O. Box 300, Salt Lake City, Utah.



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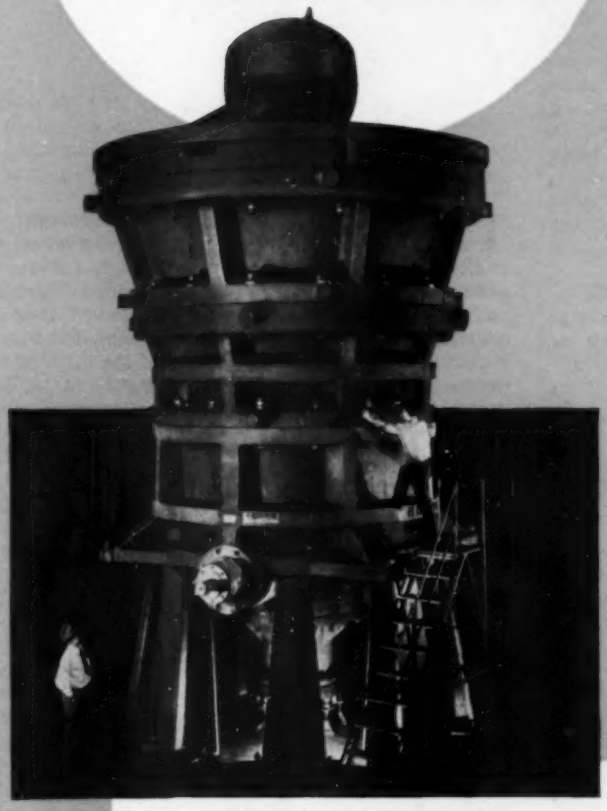
# SUPERIOR Gyratory CRUSHERS

# 29 in 3 YEARS!



**SUPERIOR** primary and secondary gyratory crushers have been making a big name for themselves since they were introduced three years ago. Twenty-six are installed and operating... three are under construction now, including a huge 60 x 109 machine — largest crusher the world has ever known.

A policy of simplifying design and controlling quality has made Allis-Chalmers the leading builder of crushers. A continuing policy of *improving* crusher design has greatly extended this leadership.

This vast backlog of crusher application experience — over 75 years of it — is always available to you when you want to make sure of a successful installation. Allis-Chalmers, Milwaukee 1, Wisconsin.

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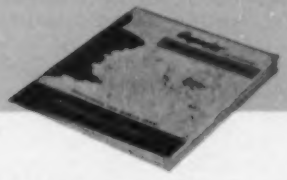

## NEW 32-Page Book Contains Helpful Crushing Data

- Packed with factual "how to" information on figuring hp requirements, impact and compressive strengths.
- Step-by-step procedures for estimating gyratory crusher sizes, capacities. Examples are worked out.
- Many other valuable facts on gyratory crusher operation . . . application . . . engineering.

*It's a book you'll want to have and keep!*

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## STOCKPILE ADDITION

PRESIDENT DWIGHT D. EISENHOWER acted quickly upon the first report submitted by his Minerals Policy Committee when he instructed the Office of Defense Mobilization to establish new long term mineral stockpile objectives.

However, the report submitted was only a preliminary work. The cabinet will get the full report soon accompanied by recommendations for a long range program which it is hoped will strengthen the domestic mining industry. Using the report, with its new approach, ODM is expected to review carefully stockpile objectives before specific purchase instructions are given to the General Service Administration. One estimate is that the new program will see Government making additional purchases of some 35 to 40 metals and minerals from domestic producers where feasible. Preference will be given to newly mined metals and minerals of U. S. origin.

Several considerations will guide the new schedule. Primary to the thinking behind the latest action is that in the event of war only a few countries which now supply the U. S. with minerals will be able to continue. It is assumed that in an emergency some minerals from domestic sources may not be available because of the effect of enemy attack. Material in the stockpile will be upgraded and refined wherever possible to make them more readily usable at a critical time.

Mining men in northern Idaho and eastern Washington voiced approval of the new program. Charles Schwab, Bunker Hill & Sullivan Mining & Concentrating Co., feels that it is at least a step in the right direction. Dale I. Hayes, western manager of American Zinc, Lead, & Smelting Co., said that stockpiling will "have the same effect as a new purchaser coming into the market, but to be effective over the long pull it must be accompanied by something that limits or restricts foreign imports and protects domestic producers from dumping."

In trading during the week when the presidential announcement was made, lead and zinc prices rose both in East St. Louis and New York. Zinc buying at the new prices was described as good and demand for lead continued. The U. S. price upturns were preceded by strength of lead and zinc in London.

## A MAN'S WORLD

MINING is a man's world—or is it? A lot of Canadian prospectors aren't too sure about the answer. Reason for the slight confusion is a little, 105-lb lady who has trekked through the Canadian bush alone, toting a 35-lb pack on her back in search of pay dirt. Mrs. Viola MacMillan, who has been elected for the 11th time as president of the Prospectors and Developers Assn., first caught the prospecting fever in 1927. She and her husband spent a summer working an uncle's claim. In 1929, when the stock market came tumbling down, Mr. and Mrs. MacMillan decided that their future lay in prospecting—so off they went into the Canadian bush.

Mrs. MacMillan, who drinks tea, is president of Violamac Mines Ltd., a lead-zinc-silver producer, and Camarillo Oils Ltd. There were a lot of lean, hungry years until the first real strike in 1934. Since then, the couple have been involved in many important ore discoveries. But Mrs. MacMillan still dreams of staking a claim on property destined to be a producing mine. Right now, she gets plenty of satisfaction from developing claims staked by others.

Mrs. MacMillan holds strong opinions concerning the place of the prospector. She is proud of the independence of action that dominates the approach of Canadian prospectors, and contrasts this "pioneering spirit" with the situation in the U. S., where she says most of the mineral seekers are employed by large companies.

## LAWSUIT

THOSE 213 suits against the Government for damages sustained during the war when the U. S. ordered gold mining operations shut down are pending before the U. S. Court of Claims. Designed to channel gold miners to production of strategic minerals, the order issued by the War Production Board on Oct. 8, 1942 closed most of the 3,107 placer mines and 220 lode mines producing gold in the U. S. and Alaska. Almost 20,000 miners were employed.

The suits against the Government ask some $120 million in damages for the closing of the mines. The Court of Claims was given jurisdiction over the cases by a special act of the 82nd Congress after Sen. Pat McCarran, Nevada Democrat, introduced a bill authorizing the court to consider the claims and waiving the statute of limitations.

The court had thrown the cases out in 1951 because petitions did not state a cause of action. Largest of the claims now before the court is that of U. S. Smelting & Refining Co. for $11.9 million. Homestake Mining Co. claims about $10.8 million.

Testimony has been taken by William E. Day, a court commissioner, in six of the suits. The entire bench will hear the cases on the legal points involved. Pending judgment on these six, the other 207 cases will be in abeyance. The six cases to be heard include Homestake; Central Eureka Mining Co., $1.26 million;Oro Fino Consolidated Mines Inc., $72,584; Alaska-Pacific Consolidated Mining Co., $209,719; Idaho Maryland Mines Corp., $5.02 million; and the claims of the Bald Mountain Mining Co., the Alabama-California Gold Mines Co., the Consolidated Chollas & Ermont Mines Inc., combined into one case totaling $737,754.

An important legal point the court will have to decide is whether the War Production Board used the Government's power of eminent domain under the Fifth Amendment to the Constitution. The amendment reads in part: "nor [shall any person] be deprived of life, liberty or property, without due

process of law; nor shall private property be taken for public use without just compensation."

While the Government did not take over the gold mines, it compelled the mines to shut, an action which the mining companies involved maintain constitutes the taking of property. The companies also contend that it was the function of the War Labor Board and not the War Production Board to divert labor from one branch of the mining industry to another. They further aver that the move was fruitless because most of the men went into other, higher paying industries, and mining retained few if any of them.

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A few off beat clicks on a Geiger counter appear to be enough to make trigger happy Toronto newspaper editors shoot banner headlines. A recent big play given uranium finds in the Sparrow Lake area about 100 miles from Toronto fell flat when veteran prospectors went into the region and found nothing more than scattered radioactivity. It is understood, *The Northern Miner* reports, that some local residents have staked claims.

Ontario Provincial Geologist M. E. Hurst, in the wake of the minor uranium rush, noted that in the case of privately owned land the owner usually holds mineral rights and the land is not open for staking. No comments on the Sparrow Lake region itself were offered by the Dept. of Mines. The press release handed out said "the reported discovery of radioactive minerals in a number of locations in the more settled parts of Ontario . . ." and failed to elaborate on time or place.

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LOTHAIR Teetor, Assistant Secretary of Commerce, urged a House Subcommittee of the Post Office and Civil Service Committee that a survey be undertaken of the mineral industry this year for release in 1955. Supporting Mr. Teetor's suggestion was John W. Boatwright, general manager of the distribution economics dept. of Standard Oil Co., Chicago. Mr. Boatwright described the last such census taken 15 years ago as having value only as a "historical document."

He argued that the survey was nonrepresentative in nature and had been taken at a time when the mineral industry was dwarfed by the "relative importance of the same industries" in today's economy. In emphasizing the need for such a survey, he reviewed the industry's position for the committee.

"This country consumes 52 pct of the free world's ferrous production, 45 pct of the free world's copper production, 54 pct of the free world's lead production, 51 pct of the free world's production of new zinc, and 65 pct of the total free world's output of petroleum and its products.

"Recent wars and mobilization efforts have served to focus attention on this nation's large current requirements in relation to its current reserves of nonreproducible materials. They have also directed attention on the fact that our raw material consumption has increased faster than has domestic materials output. Imports have increased sharply with iron and steel and ferroalloy grades averaging 24 pct of domestic consumption for the years 1948 to 1952. Net imports of other nonferrous metal ores (except gold) represent approximately one half of domestic consumption in recent years."

Mr. Boatwright noted that the number of mineral operations, by types and locations, is not available. No complete mailing list of such organizations is known. The number of operating companies, according to the executive, is also a mystery. "Principal operating expenses of mineral industries such as wages and salaries, cost of supplies, fuels, electrical energy consumption, and contractural work performed represent areas of unknowns."

Additional questions that Mr. Boatwright tossed out to the committee were: "What are the capital requirements of the mineral industries? What are the capital expenditures for exploration and development of mineral properties, plant construction, new machinery, and equipment?"

Mr. Boatwright, after listing a whole batch of currently unanswerable questions which he thought a survey might help solve, commented, "These are but some of the knowledge gaps that are rather frightening . . ."

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ACCORDING to some quarters, Federal regulation has stymied mining development on the Navajo reservation in New Mexico. The tribe is interested in attracting private capital and is reported to be making changes that it hopes will be effective. Navajo tribal engineer K. N. Garard, speaking in Gallup, says that the Navajos want to get mining on a "good, sound basis" and are trying to ease requirements for legitimate operators.

Mining on the 15.5 million-acre reservation is still almost negligible. Uranium, according to Mr. Garard, may extend over some 9.5 million acres. While coal, gas, and oil are definitely known to exist, production has been small. Shell Oil Co., however, has spent more than $4 million in getting leases and pushing exploration work. Mr. Garard is inclined to believe that Government control has retarded a tremendous coal strip mining operation proposed by a large firm. Mr. Garard states that millions of tons of coal could be reclaimed, and that a good part of this coal is near water, making practical location on the reservation of large plants needing cheap fuel.

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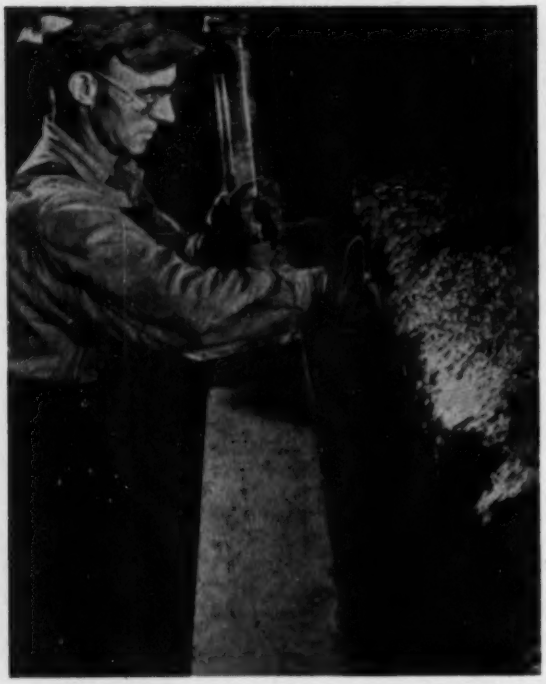
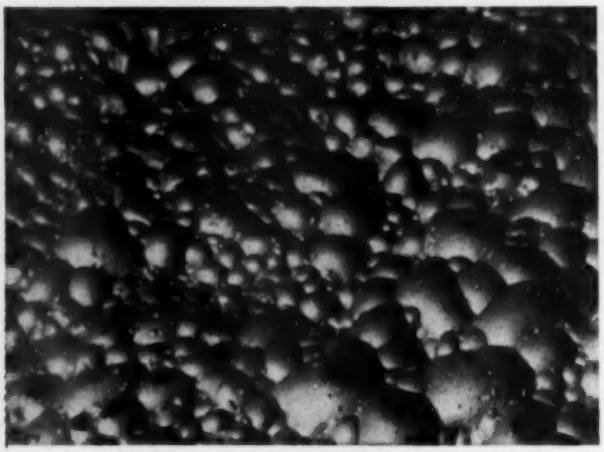


**Increased recovery and improved concentrate grade** show up immediately when Dow Xanthates go to work in your mill. This has been proved in mills all over the world where these superior Dow collectors are improving metallurgy and saving dollars.



**These Xanthates permit greater freedom** in regulating frother and collector independently because they are reliable collectors but substantially nonfrothing.

For a quality frother, however, give Dowfroth® 250 a trial. It builds hard-working froth with reduced consumption.

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# New use of modern equipment doubles profitable stripping depth — improves grade of coal

BACK in 1940, the Avon Coal Company found it was not profitable to strip more than 25 feet of overburden to reach a seam of coal. For this reason, shaft mining was used exclusively in their Minto, New Brunswick coal field.

But, today, with the help of a fleet of modern Allis-Chalmers tractors, the company now can strip up to 60 feet of overburden and then mine a 20-inch seam of coal at a profit. What's more, this new method and postwar equipment has resulted in the production of a far better grade of coal . . . has opened many new markets for Minto coal.

Ask your Allis-Chalmers dealer how modern earth-moving equipment can increase the efficiency of your program.

Much of the excavating is done by the giant HD-20G Tractor Shovel owned by Crawford Contractor's Ltd. This powerful hydraulic torque-converter driven unit combines crawler-tractor flexibility with the capacity of a four-yard shovel . . . is equally useful in stripping, loading and stockpiling.

Three Allis-Chalmers HD-5G Tractor Shovels offer the responsive bucket control necessary to skim off the narrow coal seam cleanly. The high-grade coal resulting from this precision work has won many new customers for the Avon Company.

A second HD-20 with bulldozer handles large-scale stripping and stockpiles coal. It took powerful postwar equipment like this to make strip mining practical in the Minto Coal Field.

Keeping haul roads smooth is only a part-time job for the Allis-Chalmers Model D Motor Grader. Equipped with "midship" scarifier and hydraulic rear-end loader, the D has become a most versatile handy man around the mine.

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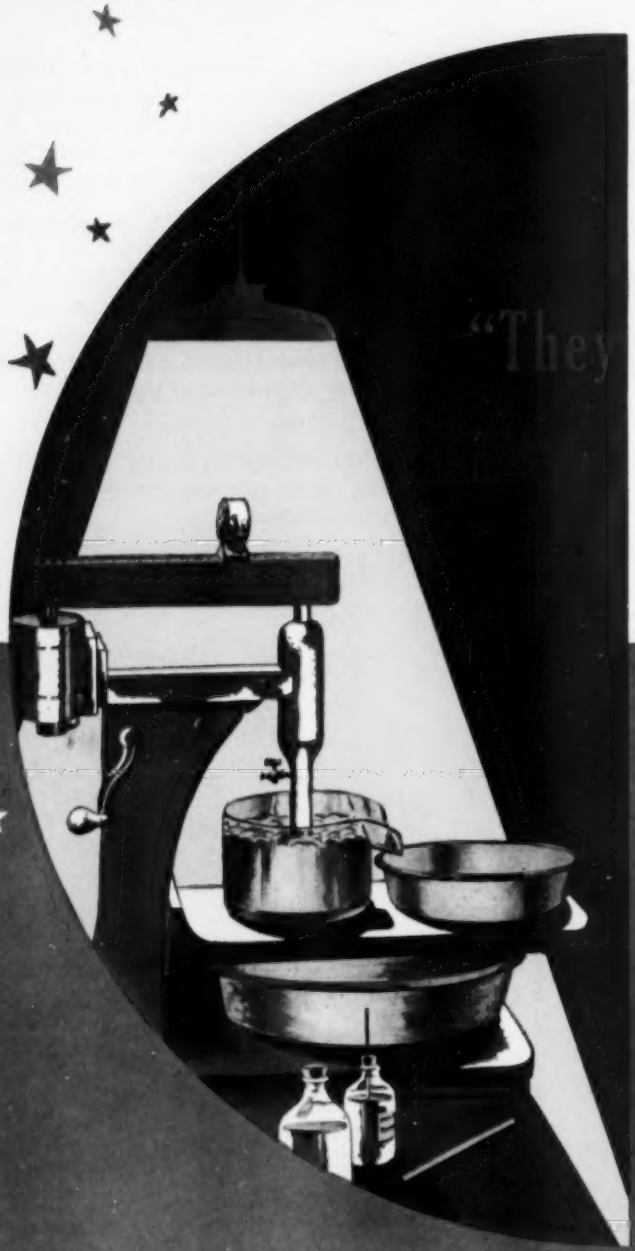

# "They Slept on the Problem"

## and learned how to produce low-iron glass sand with Cyanamid 800 Series Promoters

*Hours of testing had come to naught. Flotation with 800 Series Cyanamid Promoters would produce low-iron glass sand at Del Monte Properties but 65% recovery was far too low. Puzzled and tired, the Pilot Plant Superintendent and the Cyanamid Field Engineer decided "to sleep on the problem". But, on a hunch, they left a batch of sand to scrub at 50% solids in a lab flotation machine.*

*Next day, instead of white sand, they found a black pulp . . . and the key to a workable process. Prolonged attrition had removed an iron-bearing clay. Flotation of the scrubbed sand now yielded 95% recovery of an 0.055% $Fe_2O_3$ glass sand!*

**Del Monte Properties at Pebble Beach, California is an excellent example of the use of chemical flotation to convert beach and dune sand into four valuable, custom-built products.**

**Raw sands, comprising equal parts of quartz and high-alumina minerals, average 0.12 to 0.15% $Fe_2O_3$ and 11.5% $Al_2O_3$. Scrubbed in specially designed attrition machines, these sands are then deslimed, conditioned and the iron-bearing minerals floated, leaving behind 95% of the feed in a finished product that assays 0.06% $Fe_2O_3$ and 10.76% $Al_2O_3$.**

**Flotation reagents per ton include: 0.45 lb. sulfuric acid, 0.40 lb. fuel oil, 0.01 lb. pine oil, 0.55 lb. AERO* Promoter 801 and 0.45 lb. AERO Promoter 825.**

**Subsequent flotation in another section produces a high-grade feldspar concentrate and a practically-pure (99.07% $SiO_2$) quartz tail-**

*Trade-Mark

ing. Feed to this section can be split to control the quantity of iron tailings floated, thereby controlling alumina in the end product. Del Monte Special "77" Sand, for instance, containing only 6.50% $Al_2O_3$ and 0.051% $Fe_2O_3$ commands an active, premium market.

Cyanamid 800 Series Promoters are now being used to beneficiate glass sands, feldspar, garnet, barite, kyanite, rhodochrosite and similar non-metallic minerals. Cyanamid also offers Heavy-Media Separation and Dutch State Mines Cyclone Separator Processes, both of which merit investigation for non-metallic mineral concentration by gravity difference.

With the practical help of a Cyanamid Field Engineer experienced in up-grading low value non-metallics, you may be able to cut costs by less-selective mining, work currently sub-marginal deposits or ship higher-grade end products. Preliminary discussion entails no cost or obligation. Why not write, outlining your problem?

*It will pay you to talk with a Cyanamid Field Engineer if you mine or contemplate mining:*

Andalusite · Barite · Bauxite · Cement Rock · Coal · Chromite
Diamondiferous Ground · Dolomite · Feldspar · Fluorspar
Garnet · Glass Sands · Graphite · Gravel · Gypsum · Ilmenite · Iron Oxides · Kyanite · Magnesite · Manganese · Mica · Olivine
Perlite · Phosphate Rock · Potash · Rhodochrosite · Sillimanite
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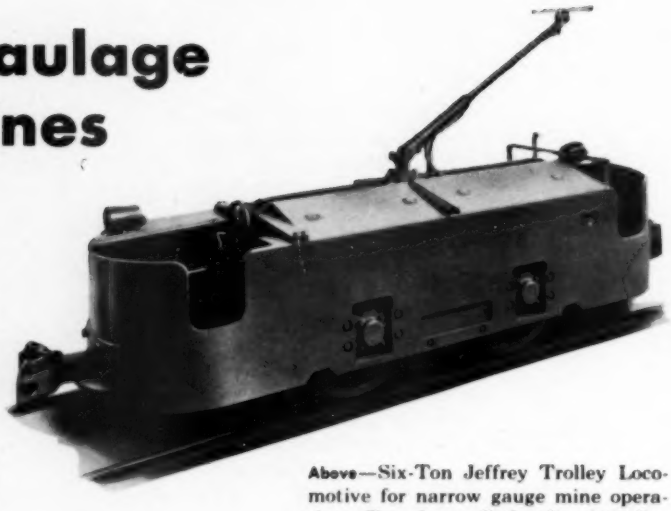
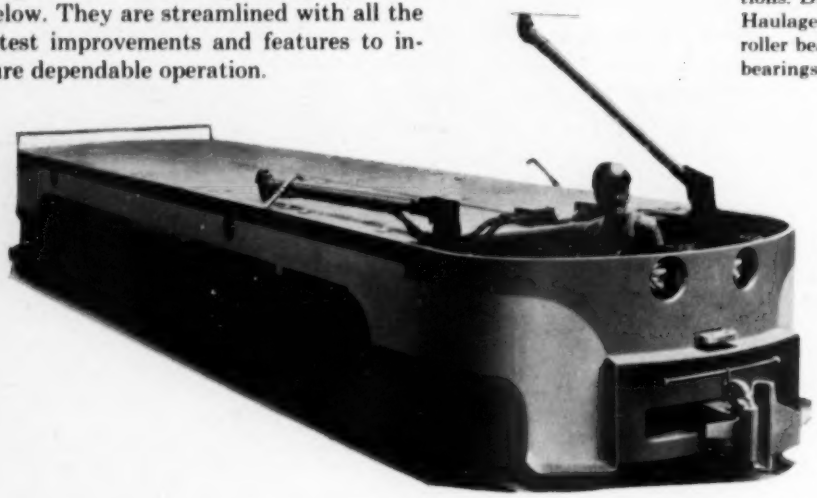
They are rugged, easy to operate and fully protected against water dripping from above or splashing up from below. They are streamlined with all the latest improvements and features to insure dependable operation.



**Above**—Six-Ton Jeffrey Trolley Locomotive for narrow gauge mine operations. Drawbar pull (level)—3000 lbs. Haulage capacity—150 gross tons with roller bearing cars; 100 gross tons plain bearings.



**Left**—Jeffrey 27-ton Eight-Wheel Trolley Locomotive. Drawbar pull (level)—13,500 lbs. Haulage capacity—675 gross tons with roller bearing cars; 450 gross tons plain bearings.

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Storage Battery Locomotives and Trammers
Combination Storage Battery and Trolley Types

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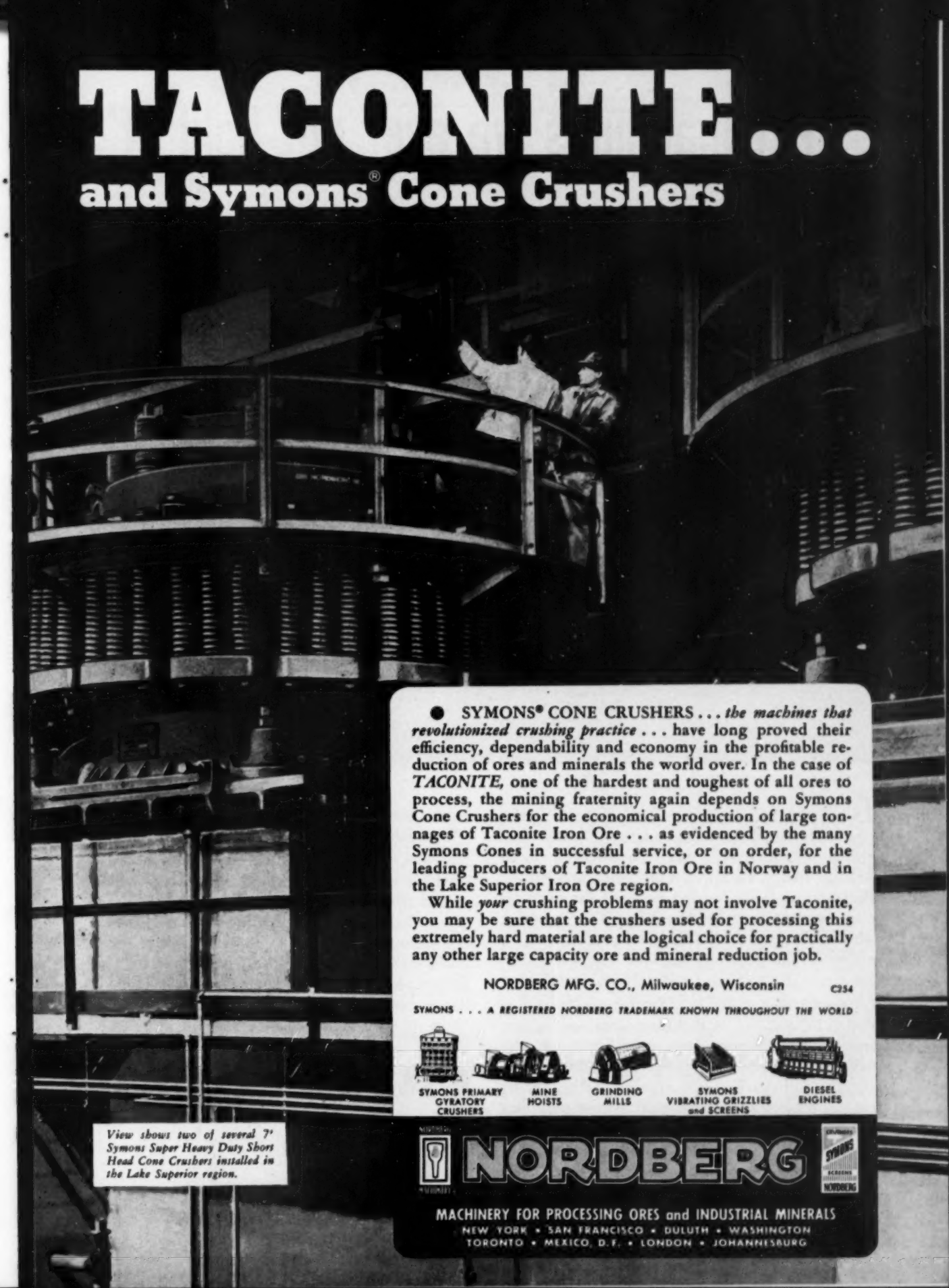
# TACONITE...
## and Symons® Cone Crushers



● SYMONS® CONE CRUSHERS . . . *the machines that revolutionized crushing practice* . . . have long proved their efficiency, dependability and economy in the profitable reduction of ores and minerals the world over. In the case of *TACONITE,* one of the hardest and toughest of all ores to process, the mining fraternity again depends on Symons Cone Crushers for the economical production of large tonnages of Taconite Iron Ore . . . as evidenced by the many Symons Cones in successful service, or on order, for the leading producers of Taconite Iron Ore in Norway and in the Lake Superior Iron Ore region.

While *your* crushing problems may not involve Taconite, you may be sure that the crushers used for processing this extremely hard material are the logical choice for practically any other large capacity ore and mineral reduction job.

NORDBERG MFG. CO., Milwaukee, Wisconsin C254

SYMONS . . . A REGISTERED NORDBERG TRADEMARK KNOWN THROUGHOUT THE WORLD



SYMONS PRIMARY GYRATORY CRUSHERS | MINE HOISTS | GRINDING MILLS | SYMONS VIBRATING GRIZZLIES and SCREENS | DIESEL ENGINES

*View shows two of several 7' Symons Super Heavy Duty Short Head Cone Crushers installed in the Lake Superior region.*

NORDBERG

MACHINERY FOR PROCESSING ORES and INDUSTRIAL MINERALS

NEW YORK • SAN FRANCISCO • DULUTH • WASHINGTON
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# "Best machines we ever got hold of"

This Caterpillar D7 Tractor is working on a slag pile, 'dozing residue from the smelter mill of Bunker-Hill & Sullivan Mining and Concentrating Co. at Kellogg, Idaho. Equipped with a matching No. 7A Bulldozer, it is also used throughout the plant for clean-up and materials handling. The company, which mines and smelts lead and zinc ores, standardizes on Cat* equipment. They own a D8 Tractor, four D7s, a D2 and a No. 212 Motor Grader.

Even in muck like this, the balanced construction of D7 and No. 7A Bulldozer maintains traction and handles heaping, high-profit loads *fast*. Its factory-built precision is protected against harmful abrasive particles by really *effective* filters, and by engine, track-roller and hydraulic system seals that keep oil and grease *in* and grit *out*.

The Cat-built Diesel Engine remains *carbon-free* throughout the power range — lugging, idling and full speed — on low-cost No. 2 furnace oil. This cuts operating costs — as does the rugged construction of this Caterpillar "team" of tractor and 'dozer. This machine is built to do *more work* at *lower cost* with *less down time* than any other in its class.

Find out for yourself why Geoffery Lyons, superintendent of transportation, Bunker-Hill & Sullivan, says, "Caterpillar makes the best machines we ever got hold of." Your nearby Caterpillar Dealer — who backs his sales with dependable service and genuine factory parts — will demonstrate the Caterpillar-built Tractor and 'Dozer that are *right* for your job.

Caterpillar Tractor Co., Peoria, Illinois, U. S. A.

**CATERPILLAR***

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# Drift of Things

LOCAL Sections have received the benefit of a revised system of appropriations which should aid them in their finances in the coming year. One important factor of this alteration is the return of half of the initiation fee of a new member to the Section to which he would belong. This should be a great incentive for the development of new membership drives.

The professional society, over and above its purpose of disseminating scientific literature, is a fraternity. According to Webster, a fraternity is "A society organized for the pursuit of some common object by working together in brotherly union." It is further described as "Men of the same class, profession, character, or tastes." True value of any society is this fraternal brotherhood.

So it is easy to see that Local Sections only stand to gain as a fraternity and a financially solvent organization. Constant interest in gaining new members is the best guarantee that AIME and Local Sections will remain strong and serve those who are its present members.

LOOKING back again at the Annual Meeting, it was unquestionably the greatest in history for the Mining Branch. But, this is in no way inconsistent, because it is the most important meeting for the professional man of the mineral industry. Men from all corners of the globe gather to discuss both technical and social advances in the industry. As do the meetings of any professional group, this get-together stimulates virtually all the scientific advances in its field. Excluding the society publications, meetings are the basic reasons for the existence of the organization. Without them, no common ground for communication exists.

But in February of each year, we all face the life and death of one Annual Meeting, and a whole new cycle has started again. So this is no time to relax because of success at the last meeting.

IN 1954, the Minerals Economics Div. has set its target on the development and publication of a book which could bear the title, *Economic Principles Pertaining to Exploration and Exploitation of Mineral Deposits*. In fact, the MED session at the 1954 Annual Meeting was keyed to this proposed handbook, forming the initial step of the project.

There is little question as to the need for a comprehensive handbook on mineral economics prepared by men of experience in the mineral industry with various specializations in engineering, law, finance, business, accountancy, etc., and edited by men of equal caliber. A letter Charles W. Merrill wrote to E. W. Pehrson points up the area of endeavor which has heretofore been overlooked and avoided.

Mr. Merrill writes: "For many years I have been impressed by the futility of the exclusively technologic or scientific approach to most mineral problems. These approaches are proper in *science* and *technology*, but in the practice of *engineering* which calls for making materials and natural sources of power useful to men through structures, machines, and manufactured products, it is necessary to meet economic and social conditions as well as scientific and technologic ones. It is this practical phase which seems to me to be overlooked by so many. As a result, fine technologic work frequently remains unapplied or awaits use by the so-called practical businessman, with little or no advantage to the technologist."

This is a real challenge MED has cut out for itself. Undoubtedly this will result in a most important work to be included in the literature of the minerals industry.

Such a project as this is something the Divisions of the Mining Branch should watch carefully, as well as boost in any way possible. Activities of this type have been at a minimum in recent years, and their revival would be a positive step for the development of the Branch.

A RECENT copy of *Internal Affairs* published by the Commonwealth of Pennsylvania contained an article describing the hazards of land surveying on the Pennsylvania frontier in 1733. The surveyor, William Webb, found that it was worth as much as a man's life to attempt to survey a large tract of 10,000 acres on the Susquehanna River between New Town (Lancaster) and Pextan (Harrisburg).

A part of Webb's account of this 1733 survey reads:

"Next morning I set out with my party for Pextan in order to meet John Taylor and the others in the hopes of accomplishing my business. Arriving at the house of John Harris in Pextan about three or four o'clock in the afternoon, at my first appearance John Harris, Joseph Brinton, John Taylor and the others, rejoiced, fearing they (the Donegallians) would have way laid me and done me some great injury, so going into the house, they informed me how John Taylor had been served, supposing him to be me, while in the surveying of the 1000 acres for the Proprietor. A man in a great rage ran in upon him and struck at him several times and hurt him very much, but being prevented by some in the company of his design of taking his blood, he (the man) swearing he would have my blood if ever he met with me."

HAVING had considerable correspondence recently with AIME members way up on the "hill" at Climax, Colo., we ran on to an interesting comment made by a Climax resident about an ex-resident. Quote: "Ed sent me a card from Florida last week. Each winter he reminds me how nice it is down there. I must remember to write him next summer."

Everyone talks at conventions, but this remark took the prize: "I was making my way back to the hotel room after the cocktail hour very nicely, but when I turned the corner in the hall, some darned fool stepped on my fingers." Meetings wear you right down to the ground. One AIME member calls this common convention ailment "hoof-and-mouth" disease, i.e., you stand on your feet all day and talk all night.

*Charles M. Cooley*

Air view shows the plant at Babbitt, Minn. Main plant is already under construction on Lake Superior shore.

# Taconite Beneficiation Comes of Age At Reserve's Babbitt Plant

by Oscar Lee

RESERVE Mining Co., owned jointly by Armco Steel Corp. and Republic Steel Corp., controls 9½ miles of magnetic taconite ore on the eastern end of the Mesabi Range lying between Mesaba and Birch Lake. The ore reserve which can be mined by open pit methods is conservatively estimated at 1.5 billion tons under a shallow, loose overburden requiring no rock stripping.

Taconite now being mined is in the upper cherty horizon. It has been metamorphosed by the intrusion of gabbro and most of the iron oxide is altered to magnetite. The nonmagnetic portion of the iron is practically all in the form of silicate. The magnetic iron is finely disseminated through the rock and requires grinding −150 mesh for clean liberation of the iron oxide from the gangue.

Magnetic iron content of the crude ore ranges from 18 to 28 pct and the average analysis as indicated by drill hole records is shown on p. 486.

OSCAR LEE is Preparation Engineer, Reserve Mining Co., Cleveland.

Ore is extremely hard and no standard type of drilling equipment has been able to do a satisfactory job. The problem has been overcome by using jet piercing method of drilling the ore for blasting. Broken ore is loaded by 5-yd shovels into 22-ton trucks for haulage 2 miles to the coarse crushing plant and the start of concentration.

Clearing and stripping of the mine was started about the middle of 1951 and the mine was opened and the main haulage road to the crushing plant was completed early in the summer of 1952. The crushing, concentrating, and pelletizing plants were first turned over in August 1952, and production of concentrate and pellets started soon thereafter.

The mine and the crushing plant are operated one shift per day and produce an average of 3000 gross tons of crushed ore per shift. The mine-run of ore containing a relatively small amount of fines and a heavy proportion of large blocks is dumped from the 22-ton trucks directly into the top of the 42-in. gyratory crusher which discharges through a chute into a 30-in. gyratory crusher. The 42-in. crusher

reduces the ore to 7½ in. and the 30-in. crusher to 3½ in. in the short dimension. The ore tends to break into slabby pieces.

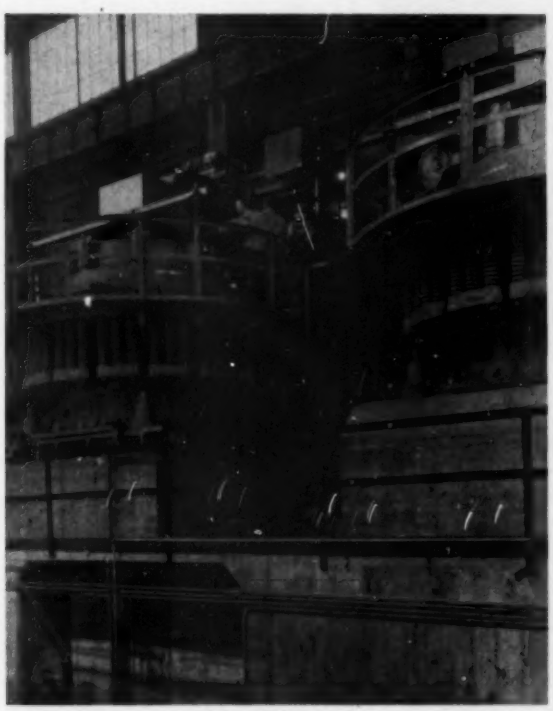
Coarse crushed ore is delivered to two storage bins from which it is conveyed to the fine crushing plant surge bins. Roll type feeders deliver ore to two 5x8-ft double-deck screens, the 1¼-in. oversize of which is fed to a 7-ft shorthead cone crusher. The product of the crusher joins the screen undersize and is conveyed to a surge bin from which the ore is fed over a roll feeder to a second pair of 5x8-ft double-deck screens. The ¾-in. oversize is crushed in the second 7-ft shorthead cone crusher set at ⅝ in. The crusher product together with the ¾-in. screen undersize is conveyed to the mill storage bins. A typical screen analysis of the crushing plant product, which is the rod mill feed, is shown on p. 486.

### Concentrating Plant

Two concentrating plant storage bins carry a 24-hr supply for the mill operation. Two Mexican pipe feeders in each bin deliver the ore to two short 36-in. variable speed belt conveyors which discharge onto a 24-in. belt conveyor carrying the ore to the rod mill. This conveyor is equipped with a weightometer to control the rod mill feed at the rate of 125 to 135 gross tph.

The 10 ft 6 in. x 14 ft 7-in. rod mill operates in open circuit and at a speed of 15.5 rpm (64 pct of critical). The normal rod load for a 130 gross tph feed is 85 tons, and the maximum size rod is 4 in. Lorain and wave type liners have been tried, but the wave type has given the best performance to date with respect to wear and rod action. The pulp density is maintained at 73 to 75 pct solids.

The first stage of concentration is on the rod mill discharge. Two 36x42-in. magnetic cobbers handle



These 7-ft cone crushers in series reduce taconite from 3 1/5 in. to 1½ in. and from 1½ to ¾ in. Final product from cone crushers is rod mill feed.

Mine and crushing plant produce 3000 tpd, operating one shift per day. Primary 42x65-in. crusher with 300-hp motor reduces run-of-mine ore to 7½ in. A 30-in. crusher completes reduction to 3½ in. Mine-run ore, containing little fines and major proportion of large blocks, is dumped directly into 42-in. crusher from 22-ton trucks.

the full load of up to 135 to 140 tph and, depending upon the grade of the crude ore, remove from 35 to 45 pct as a low grade tailing. The cobber concentrate flows directly to two 10½x12-ft ball mills operated in closed circuit with magnetic separators and 54-in. duplex spiral classifiers.

The ball mills have been operated at speeds of from 15.5 to 18.5 rpm and with various ball loads up to within 4-in. of the center line of the mill. At 15.5 rpm the mill will produce a satisfactory grind at full mill capacity with the lowest power consumption and with a saving of about 0.25 lb per ton in ball wear over the high speed (18.5 rpm).

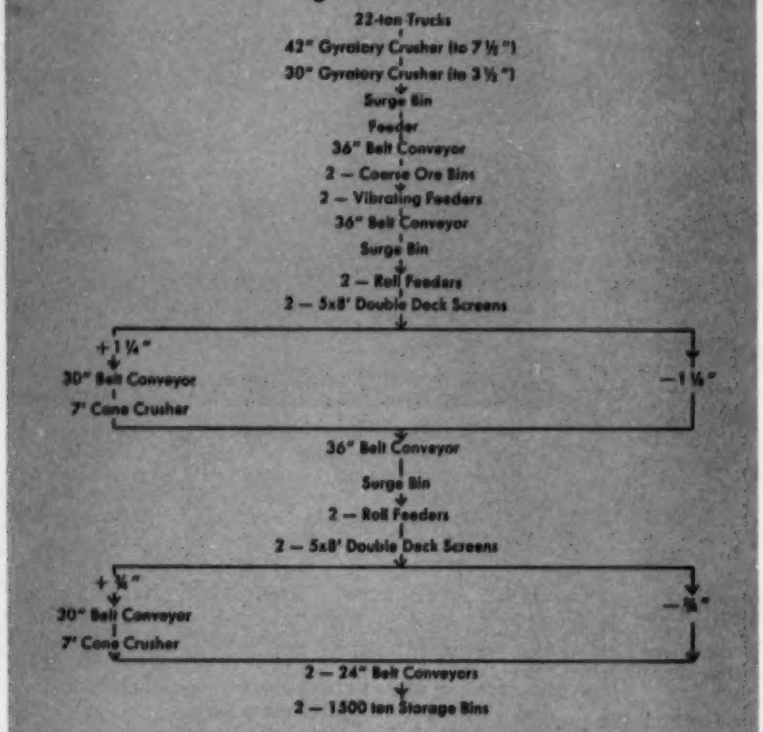
The ball mill discharge flows by gravity to the second stage of magnetic separation on two banks of three separators each. From 15 to 20 pct of the primary mill feed is eliminated as tailing and the rougher concentrate is pumped to spiral classifiers, one for each ball mill, after passing through demagnetizing coils. The classifiers have a slope of 2¾ in. per ft and the overflow is maintained at a pulp density of 9 to 11 pct solids. It is important that the classifier overflow shall carry 80 to 85 pct of −325 mesh size solids. The classifier sand is returned to the ball mills and normally this represents a circulating load of about 75 to 150 tph.

The total power consumption for grinding from ¾ in. to 80 to 85 pct −325 mesh in the rod and ball mills is under 11 kw-hr per gross ton of primary feed. The total steel consumption of rods and balls per gross ton of ¾-in. mill feed is less than 1.5 lb per ton.

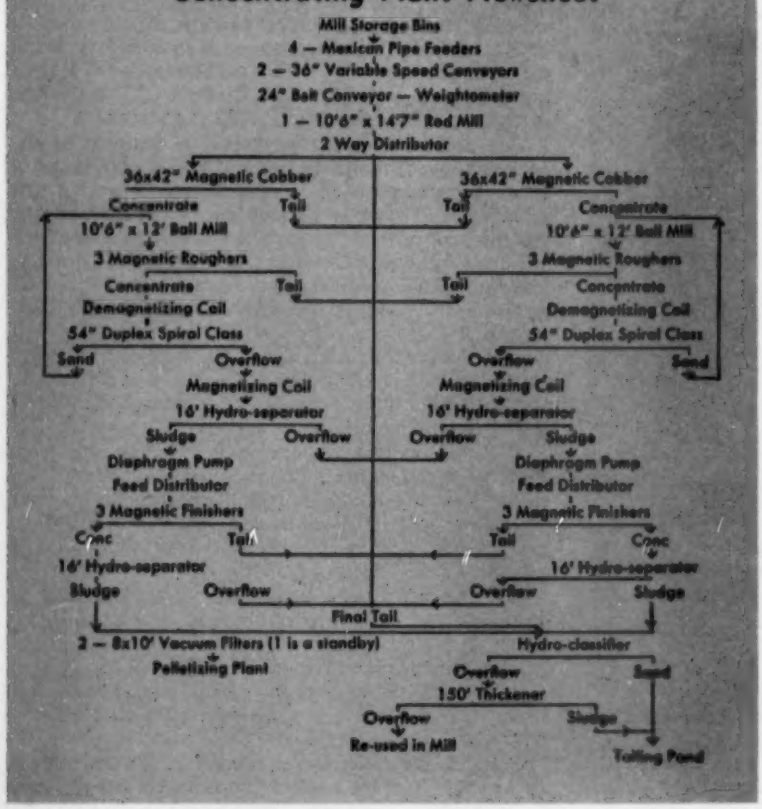
Tests are in process using four 12-in. DorrClones, completely rubber-lined, in one of the ball mill circuits. As in the case of the spiral classifiers, the sand product is returned to the ball mill for further grinding. A 66-in. duplex spiral classifier is also being tested for comparison with the other classifiers.

The classifier overflow is remagnetized on the way to two 16-ft diam hydroseparators to which wash

## Crushing Plant Flowsheet




## Concentrating Plant Flowsheet




## Analysis of Operations —From Ore to Pellets

### Ore Grade
(Based on Drill Hole Records)

| | |
|---|---|
| Total Fe | 32.0 Pct |
| Magnetic Fe | 24.5 |
| $SiO_2$ | 45.2 |
| Mn | .3 |
| $Al_2O_3$ | .8 |
| CaO | 2.3 |
| MgO | 3.0 |
| P | .05 |
| S | .02 |
| $TiO_2$ | Trace |

### Crushed Ore
(Rod Mill Feed)

| Mesh | Pct Wt. | Cum. Pct Wt. |
|---|---|---|
| +1 in. | 2.11 | 2.11 |
| —1 +¾ in. | 8.50 | 10.61 |
| —¾ +½ in. | 21.50 | 32.11 |
| —½ +¼ in. | 29.96 | 62.07 |
| —¼ +10 mesh | 19.71 | 81.78 |
| —10 +28 mesh | 7.52 | 89.30 |
| —28 mesh | 10.70 | 100.00 |

### Rod Mill Discharge

| Mesh | Pct Wt. | Cum. Pct Wt. |
|---|---|---|
| +10 | 10.53 | 10.53 |
| —10 +14 | 6.33 | 16.86 |
| —14 +20 | 8.00 | 24.86 |
| —20 +28 | 8.77 | 33.63 |
| —28 +35 | 11.07 | 44.70 |
| —35 +48 | 7.99 | 52.69 |
| —48 +65 | 6.21 | 58.90 |
| —65 +100 | 8.71 | 67.61 |
| —100 | 32.39 | 100.00 |

### Typical Concentrate Analysis

| | |
|---|---|
| Fe | 64.55 Pct |
| $SiO_2$ | 9.2 |
| CaO | .53 |
| MgO | .67 |
| $Al_2O_3$ | .55 |
| Mn | .22 |

### Pellet Analysis

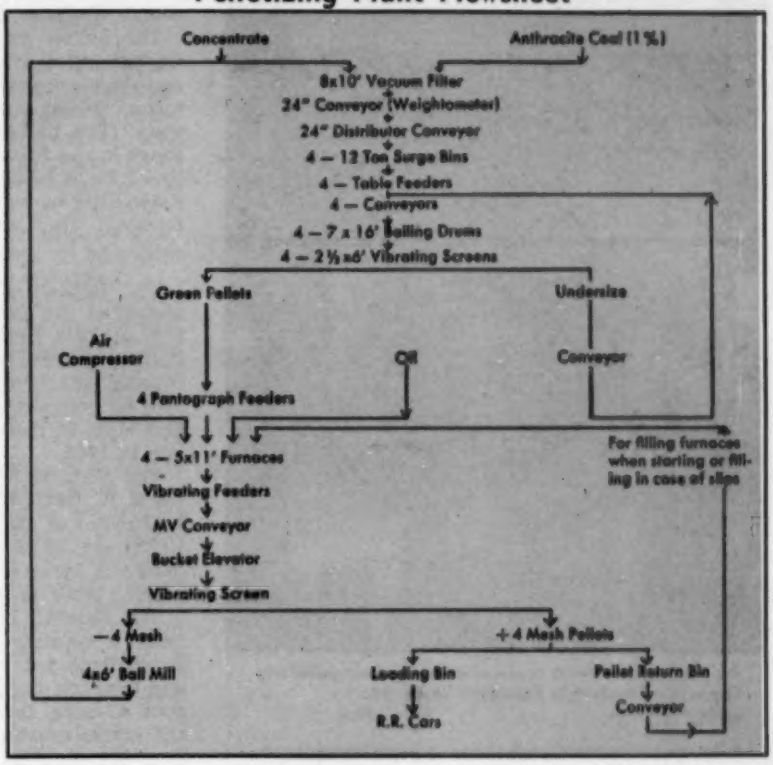
| | |
|---|---|
| Total Fe | 62.48 Pct |
| Ferrous Fe | 5.00 |
| $SiO_2$ | 9.00 |
| CaO | .50 |
| MgO | .65 |
| $Al_2O_3$ | .54 |
| Mn | .22 |
| P | .023 |

water is added. The overflow is a clean tailing and the thickened sludge is delivered by diaphragm pumps to the final stage of magnetic separation. The concentrate from the magnetic finishers goes to two 16-ft diam hydroseparators and then to an 8x10-ft vacuum filter.

This fine grinding and magnetic concentration flow sheet was developed by the Mines Experiment Station of the University of Minnesota as the result of many years of research and experimentation. The Babbitt plant metallurgical results check the laboratory results closely.

Various types and combinations of single drum magnetic separators with wash boxes, two drum machines, and belt machines are being tried in both the rougher and finisher circuits. The grade of the final concentrate averages about 64.5 pct Fe with a production of 1000 gross tons or more of concentrate per 24 hr and with a magnetic iron recovery of 90 pct. Ratio of concentration is 3:1.

## Pelletizing Plant Flowsheet




The filter operates with a vacuum of 24 to 25 in. and at a speed of from 51 to 55 rph. It has produced over 65 short wet tons of filter cake per hr at 10.25 pct moisture. The plastic filter cloth now in use has a life of well over 3 months.

Total mill tailing flows by gravity to the tailing pond. On the way, however, the coarse tailing is removed in a hydroseparator, the overflow of which flows to a 150-ft thickener. The sludge from the thickener joins the sand product of the hydroseparator and then goes on to the pond. The thickener overflow is pumped back to the concentrating plant for reuse. The total water consumption in the mill is about 7500 gpm, of which 3000 gpm is fresh makeup water obtained from Birch Lake. An ample supply of clean water is an important requirement to produce the best grade of concentrate.

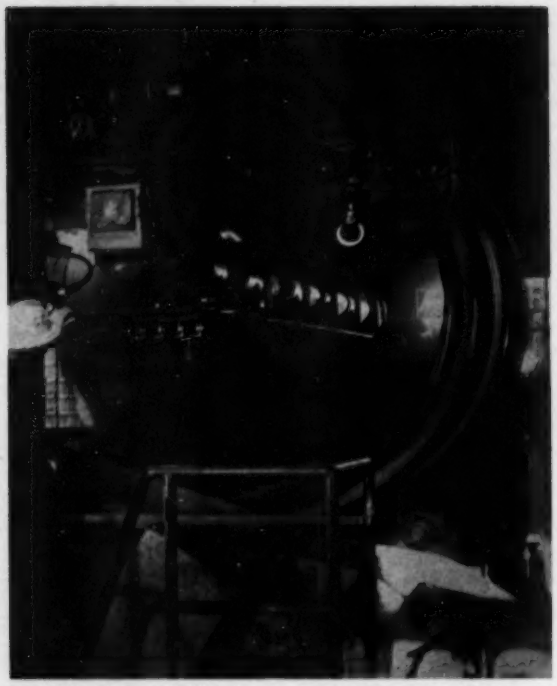
### Pelletizing Plant

Various methods of agglomerating taconite concentrate have been tried over the years, but because of the extreme fineness of the particles, 85 pct —325 mesh, the pelletizing process was developed by the University of Minnesota Mines Experiment Station not only to overcome these difficulties but to make use of the physical condition of the material.

When properly made from magnetic taconite concentrate, the final burned pellets consist largely of hematite and have a porosity of 30 to 32 pct. They make an excellent blast furnace material and are strong enough to stand up well in transportation.

Magnetic cobber makes first magnetic separation, removing 35 to 45 pct of material from rod mill.

Filter removes excess moisture from concentrate prior to pelletizing. Drum is covered with plastic cloth.



Balling drum at Babbitt is one of unique steps in pelletizing operation. This 7x16-ft drum turns at 15 rpm.

Babbitt has four rectangular shaft pelletizing furnaces, each with a capacity of 250 gross tons of pellets per day. Each furnace has its own balling drum.

To make the desirable strong, round pellets for feeding to the furnace, it is very important that the moisture content of the filter cake be under control. Normally the moisture should run between 10.0 and 10.25 pct. To further assist in making good green pellets, from 7 to 10 lb of bentonite binder per ton of concentrate is added prior to feeding the concentrate to the balling drum.

The balling drum is 7 ft in diam by 16 ft long with a slight downward slope from the feed to the discharge end. The concentrate builds up its own lining and continually operating leveling bars keep the lining in proper condition for the best rolling action of the balls.

Balling drum discharge is screened on 2 ft 6 in. x 6-ft vibrating screens, the −⅝-in. product of which is conveyed back to the feed end of the drum and serves as seed pellets. The screen oversize is delivered to the top of the pelletizing furnace by a distributing belt conveyor, motivated by a pantograph device. This system spreads the pellets uniformly over the entire cross-section of the furnace.

The heat for pelletizing is supplied by adding about 1 pct anthracite coal to the concentrate and by the additional use of 2 to 2½ gal of oil per ton, burned in combustion chambers along the two long sides of the furnace. The coal is added to the concentrate sludge ahead of the filter.

Air is blown into the lower part of the furnace to cool the pellets before discharging and also to maintain an oxidizing atmosphere in the furnace. As a result, the magnetite is oxidized to hematite with an exothermic reaction and the heat thus developed supplies approximately one third of the total pelletizing heat requirement. The temperature in the critical zone is 2300 to 2350°F and the pellets discharge from the furnace at a temperature of 200°.

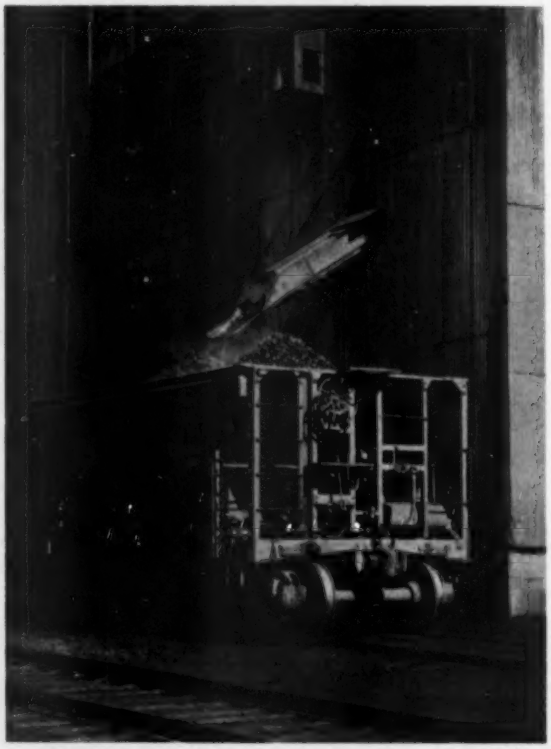
The pellets are delivered to a vibrating screen located on top of the railroad loading bin. The fines and dust are ground in a 4x6-ft ball mill and returned to the same filter which filters the concentrate. The pellets delivered to cars for shipment range in size from ½ to 1-in. diam and have a porosity of 30 to 32 pct. They are hard and strong and show little or no deformation or shrinkage during burning. They weigh from 112 to 117 lb per cu ft.

### Future Operations

The Babbitt plant, in capacity, represents one section of the new project already under construction at East Beaver Bay on Lake Superior. The initial plant, consisting of 12 sections with an annual capacity of 3.75 million tons of concentrate, is scheduled for completion by the fall of 1957, although the first eight of these sections should begin operations late in 1955.

The plant at East Beaver Bay will be known as the E. W. Davis Works in honor of E. W. Davis who, as director of the Mines Experiment Station of the University of Minnesota for over 35 years, developed the basic methods of concentrating and pelletizing taconite ore.

The Reserve Mining Co. project will ultimately reach a capacity of 10 million tons of high grade concentrate per year. In addition to the crushing and beneficiating plants, the company is building its own 47-mile interdepartmental railroad between the coarse crushing plant at the mine and the fine crushing plant at East Beaver Bay. The program also includes construction of a harbor and dock, power plant, and modern townsites at Babbitt and East Beaver Bay.



Final product starts on its way to steel mills as finished pellets are loaded at Babbitt.

# Good Files or Bad?

ENGINEERING department problems of unravelling filing systems of reference data, detail drawings, magazine tear sheets, technical records, manufacturers' catalogs—and coordinating them with the information classification systems employed by the company library and other information services—are being solved in many cases by adopting a basic classification system such as that used by *Sweet's Catalog Service* and applying its classification and indexing methods to file or bookshelf.

By this procedure the engineering department does away with the confusion, duplication, and conflict that exist between personal, department, and company library files. It establishes a pattern for regulating and distributing the potential information that piles up daily in the engineering department basket marked "Incoming."

To illustrate the simplification that is possible, the manufacturers' catalogs in Sweet's 1954 Plant Engineering File and Production Design File are divided into seven and four major product classifications, respectively. The subclassifications in the Plant Engineering File total 36; those in the Product Design File total 23. Yet these simplified ramifications of product data embrace nearly every area of engineering interest. (See boxed lists.)

1. **Materials**
   - a. metals
   - b. metal fabricators
   - c. plastics
   - d. plastic processors and fabricators
   - e. rubber
   - f. wood
   - g. glass
   - h. other materials
2. **Electrical Parts**
   - a. motors and generators
   - b. controls
   - c. other electrical parts
3. **Mechanical Parts**
   - a. transmission
   - b. flexible shafts
   - c. bearings
   - d. hydraulic and pneumatic equipment
   - e. pumps and compressors
   - f. fittings and valves
   - g. flexible tubing and hose
   - h. gaskets, packing, and oil seals
   - i. instruments and controls
   - j. lubricating systems
   - k. fastening devices
   - l. other mechanical parts
4. **Techniques and Services**

Classifications are not static. Easy adjustment each year meets ever-changing industrial information requirements. Within the framework of such a classification system it is helpful to adopt the following system of indexing individual pieces of product literature.

Under each subsection, literature is arranged in alphabetical sequence by manufacturers' names. A convenient fractional indicator to identify each piece of literature consists of three parts in the *numerator*, the major section number followed by the subsection letter; in the *denominator*, the first two letters of the manufacturer's name in upper and lower case. In case two firm names in the same subsection have the same first two letters, the third letter is added.

One of the principal advantages of this system of filing is that it is open-ended. Obsolete data can go out, without having to revamp the indicators.

1. **Mechanical Equipment**
   - a. materials handling
   - b. vertical transportation
   - c. power transmission
   - d. pumps and compressors
   - e. plate construction, tanks
   - f. pipe, fittings, strainers
   - g. valves and traps
   - h. instruments and controls
   - i. lubrication
   - j. finishing
   - k. production equipment
   - l. miscellaneous equipment and supplies
2. **Electrical Equipment**
   - a. distribution
   - b. panelboards, motors, controls
   - c. power tubes
3. **Materials**
   - a. metals
   - b. glass, plastics
   - c. masonry
   - d. wood and wood preservatives
   - e. roofing and siding
   - f. gratings, grids, floor plates
   - g. flooring, wall covering
   - h. masonry, treatments, waterproofing
   - i. paints, finishes, protective coatings
4. **Thermal Insulation, Sound Control**
   - a. thermal insulation refractories
   - b. sound control, vibration isolation
5. **Structural Equipment**
   - a. structural systems
   - b. doors and hardware
   - c. skylights, ventilators
   - d. partitions, fences, guards
6. **Plant Utilities**
   - a. power generation
   - b. water conditioning
   - c. air conditioning, heating, refrigeration
   - d. lighting
   - e. protection
7. **Service Equipment, Services**

**Example:**

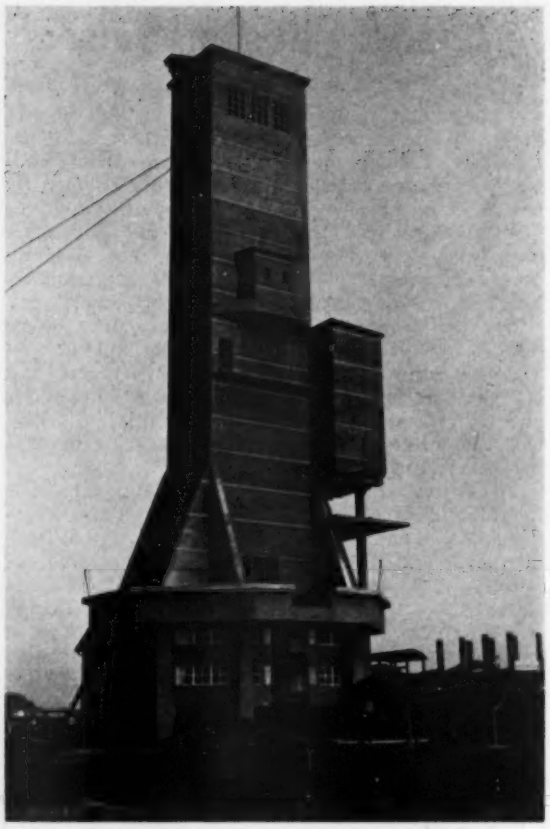
Plant engineering receives a catalog from the Acme Co. describing its line of pumps. This would be classified under section 1, subsection d and indexed $\frac{1d}{Ac}$, writing this indicator on the upper right hand corner.

Best indorsement of this idea is the source—no one man is credited with it, where it originated no one knows, nor how long ago. But, recently salesmen and manufacturers' representatives began to bring back more and more reports of its use in the field. At least 100 large firms are now adapting their files to follow the classification used by *Sweet's Catalog*, and undoubtedly many others have taken up similar systems, and expanded them as the base for the company's own information service.

# YUGOSLAVIA—

## Potential Mineral Giant

**YUGOSLAVIA emerged from World War II with its government, social structure, and economic direction changed. Before the war the country had been noted for one or two famous mines—and a lack of general mining and industrial development. This story was compiled from information obtained from the Yugoslavia Consulate in New York, and then checked with European mining authorities in the U. S. In the final analysis, the reader and time must be the judge of the validity of the material presented.**



New reinforced concrete headframe has been built at the Velenje mine in Slovenia. Estimated lignite output is 7000 tpd through two 10-ton skips and two cages. Only one hoist has been installed. Eventually, the mine will be completely mechanized with conveyors on each level.

YUGOSLAVIA is one of the smaller countries in Europe—about twice the size of Pennsylvania—but one of the richest nations in variety and quantity of minerals on the Continent. The country, just now beginning the pangs of a real industrial birth, has a mining history that goes back as far as the sixth century, B. C. Among others, the Romans exploited Yugoslavia's lead and zinc deposits, and there was intensive mining during the Middle Ages. But until now, the country's industrial development was such that it made no great demand on the mining industry for development or expansion.

Conversations with Yugoslavian officials in New York give the impression that they are interested in two things. They need money and they need trained engineers to solve their mining problems. Yugoslavia appears to be attempting to attract both foreign money and foreign technical skill. They want financial aid in the form of loans. The U. S. Government has given aid to Yugoslavia in the shape of armaments, foodstuffs, and equipment. Recently, American banks have advanced funds.

One of the big jobs facing Yugoslavia in developing the mining industry is a survey of what the country actually has in the way of a mineral potential. Until now, even those deposits which could be mined from the surface reportedly have hardly been touched. Traditionally, Yugoslavian mining has centered around minerals such as lead, zinc, mercury, iron, gold, silver, copper, and coal. Minerals whose occurrence is not apparent from casual observation, molybdenum, vanadium, cobalt, tin, tungsten, bismuth, and uranium, have until the postwar period been virtually unknown.

Yugoslavia lays claim to a wealth of industrial minerals, but their presence was discovered a comparatively short time ago. The Government points out that there has been no use for industrial minerals. As for exploration techniques, deep drilling and geophysical prospecting have been used only since the end of World War II.

### Energy Base

Yugoslavia considers its "energy base" essential to its development as an industrial nation. Resources include coal, oil, natural gas, water, and wood. Reserves are listed under three classifications: measured reserves established using modern methods and considered ready for exploitation; indicated reserves estimated on the basis of limited surveys; and inferred reserves, energy base estimated on the basis of observable characteristics, are not included.

Coal reserves are estimated to be 13.9 billion (metric*) tons, with brown coal representing 13 pct, bituminous 1 pct, and lignite 86 pct. A large portion of the country is yet unexplored and it is assumed by Yugoslavian sources that actual coal reserves are probably around 20 billion tons. According to U. S. sources, there is, broadly speaking, no anthracite in Yugoslavia. In some respects certain coals resemble U. S. anthracite. Bituminous coal is about 4.06 pct of the European and 0.92 pct of the world reserves. With such an obviously inadequate supply of better grades, Yugoslavia is emphasizing brown coal and lignite production. The first coke factory went into production Sept. 15, 1952 and includes a plant for

* Unit used throughout article is metric ton of 2205 lb.

toluol, a central tar refinery, and a lignite separator with a 2 million ton per year capacity.

Richest coal deposits are found in Serbia, Bosnia-and-Herzegovina, Croatia, and Slovenia. Major Serbian mines are located at Timok and Ibar (bituminous), Senj-Resava, Aleksinac, Despotovac, Soko Banja, Vrdnik (brown coal), Kostolac, Kolubara and Kosovo (lignite). The last three contain the largest coal deposits in Serbia.

The following mines are located in the middle Bosnian basin of Bosnia-Herzegovina: Zenica Kakanj, Breza, Mostar, Banovici (brown coal) and Kreka (lignite). They contain the largest brown coal and lignite deposits in the country. Main deposits in Croatia are in Rasa (bituminous), Siveric, Krapina (bituminous), Golubovec, Ivanovopolje (brown coal), Konjscina and Koprivnica (lignite).

While Slovenian deposits are not extensive, they are intensively worked. Best known deposits are in the Sava basin in Zagorje, Trbovlje, Hrastnik, Lasko (brown coal), and Velenje (lignite). Biggest Montenegro deposit is at Plevlje (lignite), and in Macedonia at Zivojno and Kotlanovo (lignite). Bituminous deposits are small in these two areas and there is no anthracite.

The Germans destroyed what little mechanization had taken place in Yugoslavian mines. At the war's end, mines were found with underground fires on the rampage, or flooded. Yugoslavia claims that by 1946 pre-war production levels had been reached.

### Oil Shale, Petroleum

Without inferred reserves, which to date have not been even approximated, petroleum reserves amount to about 15 million tons, oil shale another 42.6 million tons, and natural gas, 2.4 million tons. About 18 pct of the total petroleum, natural gas, and oil shale lies within the borders of Serbia. Another 25 pct is in Croatia between the Drava and Sava Rivers. Oil shale is also found on the Dalmatian coast and on the Dalmatian Islands. Petroleum predominates in Slovenia, with a small occurrence of natural gas in the southeast and in the Mura River Valley.

Macedonia is reported rich in oil shale, especially in the northeast portion. Oil shale is also found in Montenegro, with evidences of petroleum occurring along the coast. While no estimate can be made, petroleum is known to exist in the vicinity of Tuzla, Bosnia-and-Herzegovina.

Petroleum production in pre-war Yugoslavia was almost nonexistent. With the war over, it grew quickly, and between 1946 and 1951 Government figures indicate that production increased 5.4 times. Production in 1946 was 160,000 bbl. Vital in the surge of petroleum output was the reconstruction of the oil fields at Donja Lendava and Gojlo. The Nazis left the fields without technical or geological records

Yugoslavia is a federation of six republics, with the republic of Serbia including the autonomous province of Voyvodina and an autonomous region known as Kosovo-Mitohiyan.

## Yugoslavian Coal Production In Thousands of Tons

| Year | Bituminous Anthracite | Brown | Lignite |
|---|---|---|---|
| 1939 | 1,351 | 4,312 | 1,310 |
| 1946 | 757 | 3,823 | 2,224 |
| 1947 | 1,062 | 5,325 | 2,904 |
| 1948 | 937 | 6,331 | 3,420 |
| 1949 | 1,275 | 6,682 | 4,151 |
| 1950 | 1,154 | 7,204 | 4,508 |
| 1951 | 992 | 6,916 | 4,134 |
| 1952 | 1,011 | 6,842 | 4,245 |

## Yugoslavian Ferrous and Nonferrous Ore Production 1939 to 1952 in Metric Tons

| Year | Iron | Manganese | Chromium | Lead and Zinc | Bauxite | Antimony | Copper | Pyrite (a) | Pyrite (b) |
|---|---|---|---|---|---|---|---|---|---|
| 1939 | 666,813 | 5,656 | 59,527* | 774,772 | 318,594 | 18,963 | 983,903 | 78,064 | 127,991 |
| 1946 | 394,593 | 7,514 | 93,696 | 617,696 | 55,219 | 30,495 | 645,749 | ——— | 48,594 |
| 1947 | 732,715 | 12,748 | 75,754 | 739,361 | 87,629 | 35,804 | 811,668 | 175,859 | 75,703 |
| 1948 | 864,455 | 12,795 | 62,613 | 850,652 | 136,476 | 34,661 | 1,049,723 | 209,288 | 90,718 |
| 1949 | 845,913 | 13,837 | 109,120 | 1,073,562 | 345,953 | 49,077 | 954,481 | 172,033 | 72,742 |
| 1950 | 825,856 | 13,338 | 114,736 | 1,186,724 | 200,892 | 80,534 | 1,115,779 | 86,232 | 30,935 |
| 1951 | 581,352** | 12,868 | 99,639 | 1,188,590 | 453,357 | 55,088 | 1,173,199 | 113,541 | 40,338 |
| 1952 | 676,010 | 12,687 | 107,222 | 1,203,764 | 577,196 | 74,594 | 1,264,998 | ——— | 20,732 |

(a) Pyrite from concentrates, (b) Pyrite ore.
* U. S. Bureau of Mines quotes iron ore production of 581,000 tons. Other sources use 581,352 and 561,352 tons.
** *Minerals Yearbook*, Yugoslavian Government State, 44,852 tons.

and destroyed the installations. New fields, Mramor Brdo, near Gojlo, and Sumecani, are in production. Potential reserves, are estimated by the Yugoslavian Government to be about 10 million tons. Potential reserves of new fields now in production must be borne in mind as possibly being a part of this estimate. Admitting that petroleum reserves are not great, Yugoslavia feels that they are adequate for the country's present stage of industrial development. Test drillings in Ulcinj, in Montenegro, and in Banat have been promising. Many of the figures in this section of the article have been lumped together because of unavailability of more specific data.

### Iron

One thing Yugoslavia appears to have extensively is iron ore. Along with the rest of the nation's mineral and metallurgical industry, production before the war was considered sufficient. There was little or no attempt at intensive exploration. The largest deposits investigated to date have been in Bosnia near Vares and Ljubija, where about 130 million tons of ore were reported in 1937. The breakdown at the time was 30 million tons of developed ore at Ljubija (two-thirds limonite with 52 pct Fe and one-third siderite with 42 pct Fe) and about 100 million tons of hematite ores at Vares with 40 to 60 pct Fe. Serbia may also prove to have large deposits, but exploration thus far seems to have been in low key. Significant deposits, said to assay 40 pct iron, are in the area of Sumadija, in a large region between Belgrade and Zapadna Morava. The Kopaonik area is estimated to contain about 150 million tons. Other deposits are in northeast Serbia, around Majdanpek, Rudna Glava, Crnjajka, and Kosovo-and-Metohija. Additional discoveries have been made in Macedonia, while signs of ore have been observed in Slovenia, Montenegro, and Croatia.

### Ferroalloy Metals

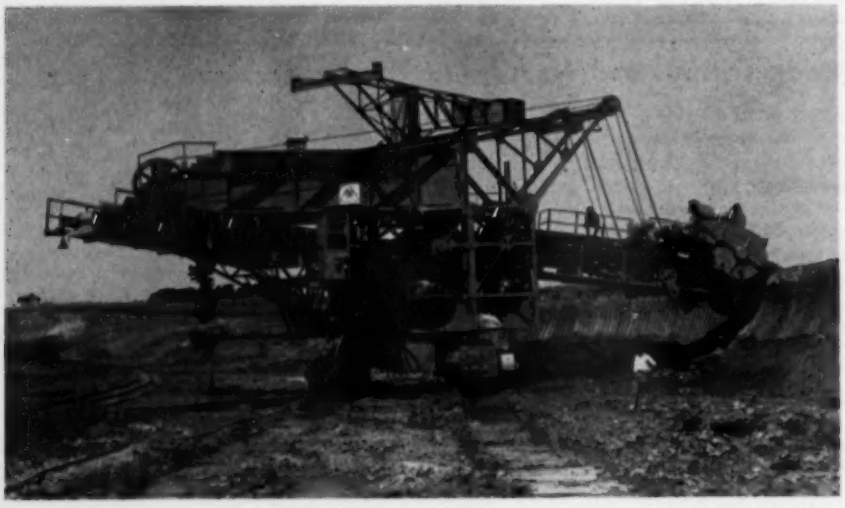
Manganese ore deposits occur across the country from northwest to southwest. The largest deposits are in Kozara, the valley of Lim, near Raska, and in the Kicevo region of Macedonia. Undisclosed reserves are said to assure Yugoslavia's iron and steel industry of a plentiful supply of manganese from native resources.

Yugoslavia claims to be the richest country in Europe in respect to chromium, found in Serbia and Macedonia. Tetovo, Sar-Planina, Kumanovo, and Velez in Macedonia are most productive Yugoslavian deposits. The ore is termed rich. Most recent estimates released by Yugoslavian information officials place reserves at approximately 1.5 million tons of chromium. Yugoslavian chrome ore is of good grade and suitable for ferroalloys. The $Cr_2O_3$ content averages between 25 and 30 pct and occasionally up to 50 pct. It also contains 12 to 16 pct iron and large amounts of silica. Mine output of ore in 1940 was about 70,000 metric tons averaging 23 pct $Cr_2O_3$. The ore yielded 30,000 metric tons of concentrates with 50 to 57 pct $Cr_2O_3$.

The Trepca mine is Yugoslavia's biggest copper producer. However, U. S. authorities feel that at the current rate of production the mine will be exhausted within a few years.

Molybdenum is found in only two European countries, Norway and Yugoslavia. Major Yugoslavian deposits are in eastern Serbia. Definitely established reserves are more than 100 million tons of ore reported to be low grade. Other parts of Serbia may also prove to contain molybdenum. In Slovenia, molybdenum is obtained as a byproduct of lead-zinc operations.

Reserves of nickel, cobalt, and tungsten ore are described by the Government as being sufficient for domestic needs although no details are provided.



The Kolubara open pit in Serbia is scheduled to produce 6000 tons of lignite per day in three shifts. A German-built wheel bucket excavator removes sandy overburden. The machine has a capacity of 5000 cu m per day and is electrically operated. Overburden is loaded by belt conveyor at upper left.

### Lead-Zinc and Copper

All lead and zinc mines now operating have been opened on the site of so-called *dead* operations. Many of them were worked by the Romans, others in the Middle Ages. Despite the high state of development of medieval mining, the deposits in the south and southwest were not closely investigated. In the face of a scarcity of technical men and inadequate processing equipment, the lead and zinc industry has managed to build a foundation. Known reserves add up to about 18 million tons of ore, running about 5 to 6 pct lead and 3 to 4 pct zinc. About half the reserves are confined to five mines—Trepca, Rudnik, Zletovo, Mezice, and Lece. Major lead deposits are between Belgrade and the Greek frontier. Major lead producers are Avala, Kosmaj, Rudnik, Kotlenik, Kopaonik, and Trepca. Lead and zinc are also reported in Slovenia, Montenegro, and Croatia.

In the only area where copper reserves have been thoroughly investigated, Bor, there are some 20 million tons. The Yugoslavians have high hopes that the Majdanpek mine will soon outstrip the productivity of Bor, now the largest European copper operation. Small deposits are also found in east Serbia and in Macedonia. Copper production in 1939 was only 983,903 tons, but by 1952 the nation produced 1.26 million tons. Copper ores at Bor, averaging slightly more than 3 pct Cu, will be exhausted in about 15 years at the present extraction rate, U. S. experts assert. Ore reserves at Majdanpek have been estimated at 100 million metric tons, but metallic copper content is only 0.9 pct. Development of the orebody is already underway.

This conveyor system is operating at Kakanj coal mine in Bosnia-Herzegovina. Yugoslavia has become intensely interested in developing its mineral industry.

Mine workers emerge from underground operations at the Zletovo lead mine in Macedonia. Yugoslavia is just beginning to bring modern mining methods into play and expects that they will have an important role in stepping up a mineral industry geared to an overall industrial program.

### Other Metals

Bauxite production in 1952 reached 577,196 tons, compared with 718,594 in 1939. Yugoslavia, it may be assumed, is attempting to get an aluminum industry going, with major reserves in Bosnia-and-Herzogovina, and others in Croatia and Montenegro. Bauxite production has increased steadily from the 1946 production of 55,219 tons.

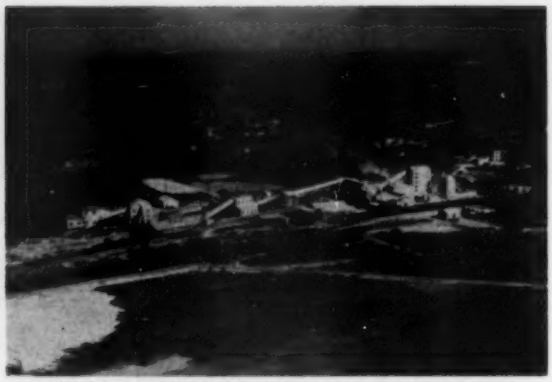
Yugoslavia ranks first in European antimony production outside the Soviet Bloc, producing about 4.5 pct of the world total. Largest mines are in Serbia, and activation of several mines has been stymied because of arsenic content.

Yugoslavia ranks third in European production of mercury, being responsible for more than 11 pct of world production. Practically all of its mercury production comes from the Idria mine which belonged to Italy from 1918 to 1944. The mine produced 504 tons in 1952, compared with 378 tons in 1939. Temporary mercury mining has been carried on in other areas of the country.

Pyrite occurs in combination with lead, zinc, and copper ores. Significant deposits have been uncovered in Serbia and Bosnia. Production in 1952 was 20,732 tons. Yearly production figures show that the 127,991 tons produced in 1939 has not been matched by the present operators. Best year was 1948 with 90,718. However, pyrite output as byproduct concentrates from complex sulphide ores is now several times greater than from straight pyrite ores.

Gold and silver are produced in some quantity but exploration has been limited. Resources of clay, koalin, graphite, asbestos, barite, mica, and other industrial minerals are claimed by Yugoslavia.

Surface facilities at Magnet Cove, Ark. Magcobar is presently mining barite about 600 ft below the old open pit workings shown here.



Barite beneficiating plant at Malvern, Ark., was the pioneer that revolutionized the refining of barite for oil field drilling muds.

# Magcobar — Mud is Their Business

## *Supply of vital drilling fluid depends on mining operation*

by Tommy Wilson

OIL well drilling fluids have become a vital part of the drilling industry during the past 25 years. From chance usage of drilling mud at the fabulous Splindletop field in 1901, drilling fluid control has become an extremely technical and exacting science.

Drilling for oil today involves exploration at depths ranging to 21,000 ft, nearly 4 miles. Geological formations encountered at these depths offer a tremendous challenge to the production, research, and service facilities of any drilling mud company.

Drilling mud has several important roles in the continuing search for oil. Some of them are:

1. Carrying the bit cuttings to the surface.
2. Allowing the cuttings to settle out of the circulation system upon their arrival at the surface.
3. Its circulation lubricates and cools the bit.
4. Forming a cake or mud sheath on the walls of the hole, thereby preventing the escape of the fluid into neighboring formations.
5. Offering sufficient hydrostatic pressure to offset subsurface formation pressures.

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The Magnet Cove Barium Corp. of Houston, Texas, furnishes the oil industry with a complete drilling mud service and operates three mines and six plants in the production of drilling fluid products. The basic drilling mud component, barium sulphate ($BaSO_4$) or barite, is found in the world's largest known deposit at Magnet Cove, Ark., about 50 miles southwest of Little Rock. Magcobar's barite refining facilities, including plants at New Orleans and Brownsville, Texas, have an annual production capacity in excess of 325,000 tons.

The principal use of barite is to increase the density of the drilling fluid, thereby increasing the hydrostatic pressure above subsurface formation pressures. This prevents intrusion of formation fluids, such as gas, oil, and salt water, into the bore hole during the drilling operation.

Barite was originally mined at Magnet Cove from an open pit. This eventually necessitated the hauling of too much waste so the company began underground operations. The orebody at Magnet Cove lies in a syncline in the shape of a watermelon cut in half: the flat surface is the ground level, the rind barite ore, and the melon represents the overburden.

LEFT: Head frame at shaft of Magnet Cove barite operation. Raw barite goes to the Malvern plant 12 miles away. CENTER: This flotation cell is at Malvern. RIGHT: Field service engineer checks the drilling mud on a drilling rig.

A core drill in Wyoming's Big Horn Mountains determines bed of bentonite about 20 ft below the surface. An exposed bed being worked is seen in the right background.

Aerial view of Magcobar's bentonite plant at Greybull, Wyo. Trucks bring bentonite ore from deposits 8 miles distant and tramway ferries material across the Big Horn River.

From the pocket the ore goes to the measuring cartridge, which holds just enough to fill a 10-ton skip. At the surface, the ore is dumped into hopper cars for shipment to Malvern, 12 miles away.

At the plant, a car shaker dumps the 50-ton cars onto a conveyor belt that carries the ore to the crusher plant. From the crusher, the ores move successively through jigs, ball mills, and classifiers and into special flotation cells. The Magnet Cove area is said to have more different minerals in one place than any other spot on earth and this flotation process, pioneered by Magcobar, is vital to producing high quality material at the Arkansas plant.

The barite recovered through flotation is thickened and filtered, dried, and roasted in a 70-ft high Nichols-Herreshoff furnace having 14 hearths.

The dried material then goes to a Fuller-Kinyon water cooler and then to a large capacity elevated storage bin. From this, the barite is packed in 100-lb sacks and moved to railroad cars for shipment to nearly 400 dealers in all parts of North America. Mud is also shipped in bulk for use along the Gulf Coast, where bulk handling facilities are in use.

As a result of an accelerated exploration program instituted several years ago, Magcobar now has the largest bentonite holdings in the world. These deposits are principally in northern Wyoming, near Greybull, where the company operates a bentonite processing plant with a product capacity in excess of 250,000 tons annually.

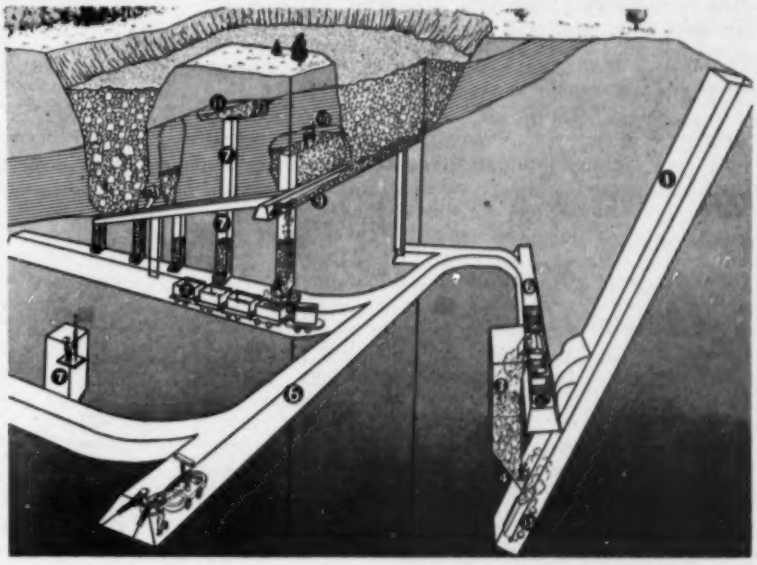
Bentonite is an important mud component for oil well drilling. It has good viscosity building properties and its ability to expand and absorb water allows it to form a gel-like substance and align itself against the walls of the hole. This cuts down on water loss to outside formations.

In addition, bentonite has exceptional lubricating properties for forming a slick coating on the drill pipe and the hole, which reduces friction and equipment wear, and also prevents corrosion.

Magcobar's deposits in Wyoming's Big Horn Basin are beds of pure bentonite averaging about 8 ft thick. The 15 to 25-ft overburden is easily removed by tractor, the ore is taken up by drag-lines, and trucks are shovel loaded.

The company had to solve a transportation problem at Greybull, about 9 miles from the present ore deposits, because the ore supply and the plant are separated by the Big Horn River. The answer was a 1600-ft tramway across the stream. Trucks deposit the ore at one terminal and the 50-cu ft capacity tram buckets dump the ore on a stockpile at the rear of the plant proper across the river.

A slusher hoist brings the ore from the stockpile to the slicer. Then an 18-in. conveyor belt moves



**UNDERGROUND LAYOUT** at Malvern in perspective view. Key numbers are: (1) incline shaft sunk in 1947; (2) trains in haulage drift (6), handle ore to pocket (3) which loads a measuring cartridge (4), filling 10-ton skips (13). Timbered scraper drifts (9) have 15-hp slushers to handle ore from shrinkage stopes (10), which are augmented with production from top-slicing in soft formation (11). Shown are the 160 and 292-ft levels now in production.

the bentonite 60 ft to the dryer. This 8x60-ft barrel dryer, manufactured by Standard Steel Co. of Los Angeles, is rated at 18 tph, and turns 3 1/3 rpm. Natural gas provides a temperature range of 150 to 1200°. The material is in the dryer less than 20 min.

From the dryer, elevators move the product to a 500-ton crude storage bin and it is gravity-fed to the 66-in., 6-roll Raymond mill. An air stream then forces the mud to a large gel storage tank which furnishes material for the 4-tube St. Regis bagging machine, with a capacity of 600 sacks per hr. The sacks are dropped to a Flexoveyor, move through a sack flattener, and on to railroad cars.

Magcobar has been conducting extensive exploratory drilling operations on its holdings in Wyoming. A 12-B Joy core drill, with a 600-ft capacity, is used, and average holes are 50 to 60 ft deep.

Other barite refining plants in New Orleans and Brownsville, Texas, are located on or near deep water facilities and receive much of their raw ore from foreign deposits. These mills also ship a large percentage of their production overseas.

# Gain in Mineral Engineering Enrollment Only Half That in All Engineering

by William B. Plank

STATISTICS just released by the American Society for Engineering Education and given in the table, show that the total current enrollment of 200,227 in the 220 engineering schools of the U. S. and Canada represents a gain of 9.8 pct over a year ago, while the mineral engineering enrollment in the U. S. of 9826 shows a gain of only 4 pct in that field.

The spurt in the mineral group shown last year is thus slowed down to less than one half of that in the whole engineering student body. Last year, it was growing more rapidly than the whole engineering group.

This situation was foreseen last year when for the first time in 5 years the freshman mineral engineering class was the largest of the four classes. This year the entering class of 2617 is 12.5 pct larger than last year, but the senior class is 6.5 pct smaller than last year. It will take 3 years more to bring the classes into the normal ratio with each other.

An idea of the current relative appeal of the various mineral engineering branches to our young college men is seen by the changes in the freshmen groups over a year ago. They all, except one, show gains over a year ago, as follows: mining 19 pct gain, metallurgy 2.3 pct loss, petroleum 25 pct gain, ceramics 2 pct gain, and geology 23 pct gain.

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**Engineering Student Enrollment Comparison 1947-48 to 1953-54**
**Undergraduates and Graduates**

| Courses | 1947-48 | 1949-50 | 1950-51 | 1951-52 | 1952-53 | 1953-54 |
|---|---|---|---|---|---|---|
| Mining | 2,459 | 2,223 | 1,607 | 1,338 | 1,168 | 1,089 |
| Metallurgical | 4,121 | 3,887 | 3,511 | 2,996 | 3,085 | 3,159 |
| Petroleum | 4,665 | 4,175 | 3,321 | 2,699 | 3,448 | 3,772 |
| Ceramic | 1,108 | 998 | 886 | 667 | 579 | 557 |
| Geological | ? | ? | 1,349 | 1,027 | 1,173 | 1,249 |
| Total Mineral Engineers— | | | | | | |
| United States | | 11,283 | 10,674 | 8,727 | 9,453 | 9,826 |
| U.S. and Canada | 12,353 | | | | | |
| Chemical | 26,972 | 19,976 | 16,323 | 14,079 | 15,026 | 15,858 |
| Civil | 31,849 | 29,109 | 24,505 | 21,801 | 22,393 | 23,075 |
| Mechanical | 56,551 | 45,632 | 35,347 | 30,420 | 32,791 | 35,097 |
| Electrical | 56,408 | 45,711 | 34,105 | 29,966 | 32,848 | 37,633 |
| Industrial | ? | ? | ? | 6,578 | 6,643 | 6,786 |
| Other Engrs. | 68,117 | 68,001 | 59,308 | 36,123 | 39,364 | 43,557 |
| Total Engrs., ECPD | | | | 147,694 | 158,518 | 171,832 |
| Other U.S. Engrs. | | | | 17,943 | 18,031 | 21,501 |
| Total U.S. Engrs. | | 219,712 | 180,262 | 165,637 | 176,549 | 193,333 |
| Canadian Engrs. | | 6,821 | 4,285 | 5,433 | 5,812 | 6,894 |
| Total Engrs. U.S. and Canada | 252,250 | 226,533 | 184,547 | 171,070 | 182,361 | 200,227 |

**First Degrees Conferred All Engineers, U. S. and Canada**

| | |
|---|---|
| 1942-43 | 14,714 |
| 1943-44 | 11,155 |
| 1944-45 | 4,724 |
| 1945-46 | 8,219 |
| 1946-47 | 19,272 |
| 1947-48 | 30,018 |
| 1948-49 | 46,934 |
| 1949-50 | 54,441 |
| 1950-51 | 43,762 |
| 1951-52 | 31,660 |
| 1952-53 | 25,332 |
| 1953-54 | 26,740 |

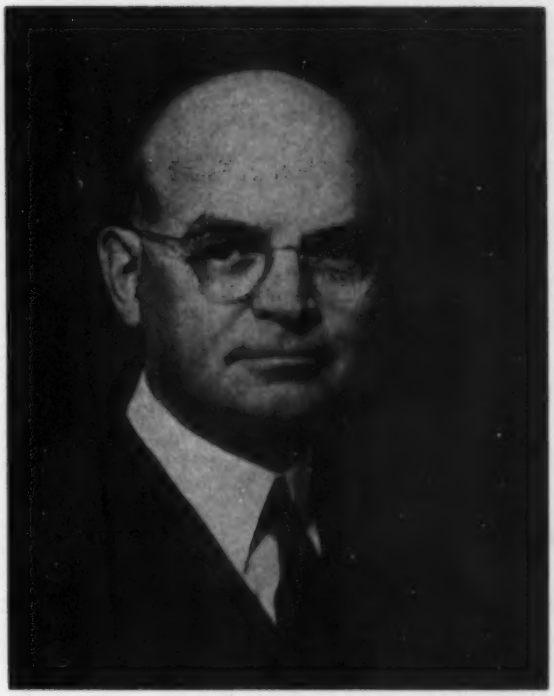
**Undergraduate and Graduate Engineering Enrollment, U. S. and Canada, 1953-54, 220 Schools**

| Schools | Courses | Fresh. | Soph. | Junior | Senior | 5th Yr. and Others | Total Under Grads. | Graduate Stud's | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| 29 | Mining | 292 | 222 | 238 | 270 | 15 | 1,037 | 52 | 1,089 |
| 47 | Metallurgical | 496 | 523 | 482 | 558 | 242 | 2,301 | 858 | 3,159 |
| 23 | Petroleum and natural gas | 1,337 | 845 | 690 | 668 | 78 | 3,618 | 154 | 3,772 |
| 14 | Ceramic | 123 | 128 | 78 | 116 | 16 | 459 | 98 | 557 |
| 23 | Geological | 369 | 266 | 219 | 253 | 10 | 1,117 | 132 | 1,249 |
| | Total Mineral Engineers U.S. | 2,617 | 1,984 | 1,695 | 1,865 | 361 | 8,522 | 1,304 | 9,826 |
| 108 | Chemical | 4,362 | 3,531 | 2,385 | 2,162 | 989 | 13,429 | 2,429 | 15,858 |
| 138 | Civil | 5,843 | 4,989 | 4,182 | 3,926 | 1,942 | 20,882 | 2,193 | 23,075 |
| 134 | Mechanical | 8,988 | 7,721 | 5,970 | 4,981 | 3,730 | 31,390 | 3,707 | 35,097 |
| 137 | Electrical | 9,280 | 7,985 | 5,436 | 4,460 | 3,765 | 30,916 | 6,717 | 37,633 |
| 60 | Industrial | 1,100 | 1,304 | 1,147 | 1,289 | 386 | 5,226 | 1,560 | 6,786 |
| | Other Engineers | 5,413 | 4,128 | 3,062 | 3,037 | 1,813 | 17,453 | 3,253 | 20,706 |
| 86 | Unclassified | 14,879 | 1,311 | 108 | 10 | 6,300 | 22,608 | 243 | 22,851 |
| 149 | Total Engrs. ECPD Schls. | 52,482 | 32,953 | 23,975 | 21,730 | 19,286 | 150,426 | 21,406 | 171,832 |
| 61 | Other U.S. Engr. Schools | 7,996 | 4,093 | 2,817 | 2,428 | 2,965 | 21,299 | 202 | 21,501 |
| 210 | Total U.S. Engineers | 60,478 | 37,046 | 26,792 | 24,158 | 23,251 | 171,725 | 21,608 | 193,333 |
| 10 | Total Canadian Engineers | 2,244 | 1,754 | 1,203 | 1,216 | 245 | 6,662 | 232 | 6,894 |
| 220 | Grand Total U.S. and Canada | 62,722 | 38,800 | 27,995 | 25,374 | 23,496 | 178,387 | 21,840 | 200,227 |

# The Daniel C. Jackling Lecture

## The Award —

*An annual invitational address by an outstanding man in mining, geology, or geophysics who has contributed significantly to the progress of technology in these fields.*



## First Lecturer —

**RENO H. SALES**

## The Presentation —

*by Fred Searls, Jr.*

Our colleagues cannot in the future earn reputations and medals for achievements in milling and smelting ore and for successful management of mining companies, if some one doesn't keep finding and mining the ore to mill and smelt and to provide the basis for the good management. Good ore seems sometimes to be quite helpful to good management, and good ore is not as easy to find as it used to be. And there are still *more* reasons, why—when this honor had been decided upon and named for Mr. Daniel C. Jackling—it should be initially conferred on Reno H. Sales.

The terms of reference of the award are that it should be conferred upon an individual working in the fields of mining, geology, geophysics, who has made an outstanding contribution to the progress of technology in one or more of those fields. And in this initial year (the earlier years are the easiest) just that was done. I think I could get away with it amongst the old-timers of my generation if I say that this time they made the award to *the* individual, who made *the* outstanding contribution. But, as Al Smith used to say, "Let's look at the record."

Really, the record is mixed up a little with extra-lateral litigation—the old-time "apex cases" under Section 2322 of the Revised Statutes. Reno Sales doesn't like such litigation, but there is little question that the urgency, generated by conflicting claims of intra-limital and extra-lateral rights, and consequent necessity for committing to records and maps the complications of Butte structure, did advance—and by several years—the first continuous, accurate, systematic, and scientific portrayal of the geological and mineralogical details of what is, after all, the most important and the most complicated copper district—at least in North America.

Prior to Sales' time, some of the most eminent of geologists often waived details. One geologist took the judge to the window to show him the Rarus fault going through a notch in the Continental Divide. The entertaining testimony in the Bluebird litigation was as perfect in literary style as it was innocent of the criteria by which faulting and lack of continuity of vein structure are now recognized.

At any rate, this need for an accurate record of structure was in the background—to whatever extent it was, or was not, the etiological agent—for formation of the Geological Department of the Amalgamated Copper Co. in and about the year 1900. Charles W. Goodale was at that time the head of the Boston & Montana, and John D. Ryan succeeded William Scallon as the president of Anaconda Copper Mining Co. in 1905. Horace V. Winchell, for years a specialist in extra-lateral litigation, was perhaps the man who at that date had the vision, the persuasive weight with the management, and the willingness to defend the idea of large current expenditures (as then viewed) for a complete and sys-



*The Transactions papers appearing in Mining Engineering during 1954 will subsequently appear in AIME Transactions Vol. 199 and may be permanently referenced to that volume.*

tematic Geological Department, for which there was no real precedent in the industry. Brunton, consulting engineer for the Amalgamated, backed him up. At that, the department started to function with one geologist, one assistant geologist, and a draftsman. In 1913 there were about 11 geologists, in 1928 15 geologists, 44 engineers, and 67 samplers.

But Sales, who took over from Winchell in 1906, is the man who made it tick. He graduated from Montana State College at his home town in Bozeman (in 1898) but although born in Iowa went on to Columbia, where he received an E. M. degree in 1900. He immediately went to work for the Boston & Montana under Mr. Goodale. By 1913, Sales published his *Ore Deposits at Butte, Montana*, which was eagerly adopted by the Clark and North and East Butte operators as a great advance over Weed's Professional Paper, which—though published in 1912—represented work done before 1906. The Anaconda Geological Dept. was very soon accepted in every camp in the country as a model whose methods were to be used to as full an extent as the production of smaller districts warranted. Sales said and wrote as early as 1927, "The viewpoint of the mining geologist and his objective is to find all of the ore in a district at a minimum of development and mining cost."

One of the reasons his methods spread so rapidly is that they were early put at the disposal of the leading educators in geology, again through the employment of the latter as professional witnesses in Butte litigation. He instructed the instructors. Leading authorities from universities studied Anaconda maps, took Anaconda notebooks underground, made notes as nearly like Reno Sales' notes as they could, and returned to their classes to spread the method, until now there is no other, and it takes someone like me to realize that there was ever any other way. It wouldn't be right to name names, but I have waited while an eminent and highly respected professor of geology occupied the time of the Court, and of a suite of highly-paid lawyers and experts, for twenty-two minutes by the clock while he hunted through 175 pages of handwritten underground notes in order to answer a question in cross-examination. The art of study of the structure of developed ore deposits belongs to two periods—one pre-Reno Sales, and the other post-Reno Sales—and the second will endure.

Nor is this his first honorary award. He received the Penrose Medal from the Society of Economic Geologists in 1939 and the Egleston Medal from Columbia in 1942.

That isn't all, but the rest is so new that you all know all about it. Reno retired as active head of Anaconda's Geology Dept. Jan. 1, 1948. He has never been very patient with poor observation or faulty geological reasoning. When Reno corrected some earlier work of others in his 1948 paper with Meyer, Hulin commented: "The authors are certainly to be congratulated, and the presentation and publication of this paper unquestionably marks a tremendous step forward in our understanding and knowledge of wall rock alteration." And Johnson: "This paper did not come from a university; it did not come from a governmental institution; it came from a mining company."

Sales has added more, not only to our knowledge of ore deposits, but to the attitude and methods for their successful study, than any man of any age. Usually, prior to Sales' time eminent geologists, even in this country, and many of the early members of our own Survey—and I except a few like G. K. Gilbert—after some observation, consideration, and thought, announced theories first and adduced certain evidence to confirm their ideas. But with Sales' department came the idea, the methods, and the insistence on a new technique. "Let's look at it. Put it all down correctly on a piece of paper, including details. What are the facts? How do you explain this feature and that one, etc.?" It is, I think, not too much to say that the approach revolutionized the economic mining geology of 40 years ago. Until recently mining geology has been largely structure, faults, zoning and rock alteration.

From the ranks of the young geologists, and also from the ranks of the geophysicists, will be drawn future Jackling Award Lecturers. A few of them are very, very sharp, but I believe they can draw from this, our First Lecturer, much to their advantage, if they will absorb his passion for careful and meticulous observation, and his patience in waiting to announce a conclusion until the evidence is in and carefully weighed.

## *The Acceptance —*

### *by Reno H. Sales*

I deeply appreciate this high honor, coming from a great organization whose written history will be a record of great achievements and progress in the arts of mining and metallurgy, not only in this country but throughout the world. I can say only that from my first days in the mines at Butte up to now my goal has been to do all within my capabilities to make geology useful and helpful to the prospector, to the miner, and the operator, to the end that more deposits of useful metals be found and that the maximum of metal recovery be made from mines and districts in the process of development.

I am proud of the name of Jackling on the medal because the name D. C. Jackling will live always in the history of copper mining. How well he deserves his title "the father of the porphyry coppers."

I shall treasure the medal, and carry with me always a deep feeling of gratitude toward this worldwide organization and its membership for doing me this very great honor.—I thank you very much.

### 1954 Award Committee

E. P. Pfleider  E. D. Gardner  LeRoy Scharon  J. D. Forrester  Guy Bjorge  Harrison Schmitt  Herbert Hoover, Jr.

*The First Jackling Lecture*

# Genetic Relations Between Granites, Porphyries, And Associated Copper Deposits

by Reno H. Sales

EVERY mine manager, mine geologist, and every prospector in the field who appraises the future of mining properties does so on the basis of a theory of ore deposition whether he recognizes this fact or not. Wherever the ultimate value of a mine or prospect is dependent upon undeveloped ore, any estimate by an engineer or geologist necessarily involves a theory of origin of the deposit. In view of these facts the importance of a thorough understanding of the genesis of ore deposits cannot be overestimated. It well may be that the greatness of our country will depend upon finding reserves of natural resources as yet undiscovered.

The genesis of ore deposits offers a fascinating field for study and investigation. This is attested by the large number of geologists who have written at length on the subject. For progress made toward a better understanding of ore genesis we owe much to Kemp, Lindgren, Ransome, Vogt, Emmons, Spurr, Graton, and a host of others. Within my own experience, I have attempted to apply in practice the various concepts and theories that have been advanced by these men.

Because of the fact that most nonferrous metal deposits are related to igneous activity, many leading authorities, notably Bowen, Fenner, and Ross, have contributed greatly to our knowledge of the origin of ores. These petrologists postulate that through processes of fractional crystallization, a granite magma differentiates into successively more acid phases from which, through further crystallization, the solutions responsible for ores finally emerge. It is stated that these solutions find their way into fissures in the solid hood, then ascend to near surface zones where they deposit their mineral load. This appears logical and sound, but as applied to the copper deposits to be considered here today, the vital role played by the so-called *porphyry* intrusions as an intermediate step in the process seems to have been overlooked.

The author believes all geologists will agree that theories involving ore solutions and their origin should be based as far as possible upon available facts. Unfortunately, the facts at source points are not disclosed for observation. The next best procedure, then, is to project known information to the assumed source, but any theory so evolved not in full accord with observed field relations should not be accepted as final. Therefore, in our search for answers to problems involving the nature and origin of ore-forming solutions, we must examine not only the structure and mineral composition of the ores and the rocks enclosing them, but also wall rock alteration effects and any other factual evidence available bearing on the problem. However, we must never lose sight of the fact that the vertical range of mineral deposition open for examination and study in most deposits may be small by comparison with the distance from the solution source to the zone accessible to the observer. This is unquestionably true with respect to most hydrothermal vein deposits of copper.

Mineral zoning is a recognizable feature common to many mineral deposits, especially of the fissure vein type. Zoning may be present but obscure where complex structural conditions prevail, or where there have been successive periods of fissuring and mineralization. Obviously, conclusions as to the nature and composition of hydrothermal ore solutions at the point of origin, based upon observation of a limited vertical range in the whole mineral depositional column from source to orebody, are subject to error. To illustrate, at Butte nearly 5000 ft of vertical mine development has exposed a clear mineral zoning picture. If underground mine development up to the present time had been confined to the first 1800 ft of depth in the so-called peripheral zone, the vein minerals exposed would have included quartz, rhodochrosite, rhodonite, and sphalerite, with subordinate galena and pyrite, all in association with extensively argillized wallrock containing calcite veinlets, with very minor sericite

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along vein boundaries. It is difficult to believe that a theory of the nature of the ore solution at its source, based upon the facts disclosed in the 1800 ft of vertical range, would have been the same as is now postulated after taking into account also the facts disclosed at deeper levels where wide zones of sericitic alteration enclose rich copper ores which consist of chalcocite, enargite, bornite, pyrite and quartz.

Earlier literature on ore deposits, in the main, supported the theory that successive zones of sericitic and argillic alteration are products of separate solution surges of different chemical composition and that sericitic alteration is solely a product of alkaline solutions. However, it is believed that at Butte the ore solutions arriving at deepest points now open to observation were probably acid and that during their upward journey they produced, simultaneously, successive bands of sericite and argillic clays in the wall rock outward from the fissures. Throughout the observable vertical range of ore deposition, the alteration pattern is the same qualitatively, but quantitatively, sericite greatly predominates over clays at levels nearest the solution source, while the reverse is true at greater distances from the source. Here again, as with vein mineral composition, Butte illustrates clearly that errors may creep in if the nature of a primary ore solution at the point of origin is judged from wall rock alteration effects at a single point of reference, or from any zone of limited vertical range far distant from the solution source.

The problem of the origin and nature of the ore solutions responsible for copper deposits genetically related to granites and intrusive porphyries is, as already has been stated, far from simple. All are of magmatic origin, but in means and methods of transfer of their mineral content from the depths wholly different characteristics may be exhibited; therefore generalized statements are subject to error. In sharp contrast, where generalizations may be made with confidence, the copper deposits of Butte and the Magma copper mine at Superior, Ariz., are good examples. Both are of hydrothermal origin associated with quartz-porphyry dikes. In mineral content they are the same, qualitatively, consisting of chalcopyrite, bornite, enargite, chalcocite, sphalerite, rhodochrosite, quartz and pyrite. The ore fluids, containing in abundance copper, zinc, arsenic and manganese, with silica, iron and a high sulphur content, effected the same type of wall-rock alteration. Thus, based on mineralogy and wall-rock alteration the ore solutions at Magma and Butte are considered to have been similar in character and composition. As to source, both followed intrusions of quartz-porphyry. At Butte, granite encloses the orebodies. At Magma, underlying granite may be inferred with good reason because of outcropping granites at short distances to the north and west.

But the fact must not be ignored that even with ore solutions of similar chemical composition at the source, the resulting ore deposits may differ widely in physical or mineralogical character because of the influence of wallrocks of varying chemical composition, or because of the nature and availability of channelways for solution travel. Where ore solution channels intersect limestone formations, massive sulphide replacements are the usual result, as at Bisbee, Bingham, and Morenci, for example. The Butte veins are typical of fissure vein deposits in granite or similar igneous rocks of relatively uniform chemical composition. It sometimes happens, however, that there has been no well-defined premineral fissuring of the rock formation containing the orebodies at or directly above the solution source. Under such a condition, which prevails over the Cananea district in Mexico, breccia-pipe structures are formed by solutions or gases acting under high pressure, and these breccia-pipe structures present the only avenues of escape for the ore solutions derived from deeper magmatic sources. And before making direct comparisons of districts we should ask ourselves this question: Which segment in the vertical range of solution activity between the magmatic source and the outer limits of the ore deposit has been made accessible to us by erosion? For example, had there been less erosion, Morenci might not have been developed as porphyry copper but only as a district of replacement orebodies in sedimentary rocks.

Examples for consideration here are certain types of copper deposits known as porphyry coppers, and their near relatives, Butte and Chuquicamata. As already indicated these are of igneous origin and directly associated with what are commonly designated quartz-porphyries or monzonite-porphyries. The economic importance of this class of deposits may be judged by the fact that during the past twenty years they were the source of more than 85 pct of the copper production of the United States. For the purpose of this analysis it will be convenient to divide these important copper occurrences into three general types: 1—magmatic, of which the Colorada orebody at Cananea is the outstanding example; 2—late-magmatic, represented by the Ajo and Potrerillos deposits; and 3—hydrothermal, of which type Butte is the classic example.

*Magmatic Type:* The Colorada orebody at Cananea, Mexico, is intimately associated with quartz-porphyry intruding andesitic rocks. The orebody is very high grade, having produced over 750 million lb of copper. The primary ore is composed of massive glassy quartz, phlogopite mica, chalcopyrite, bornite, molybdenite and pyrite, with minor covellite and chalcocite. There is no orthoclase associated with the ore minerals nor is there any evidence of a post-porphyry introduction of orthoclase into the rocks enclosing the ore.

It appears beyond question that the mineral content of this "cup-shaped" deposit existed as a fluid ore-magma mass at its present position and there underwent a process of segregation, quartz being the first to crystallize out in solid form, followed by mica, copper sulphides, molybdenite and minor quartz. The enclosing wall rocks were altered locally, and a thin halo of copper enrichment of the wall rock was effected by injected dike-like veinlets of quartz and chalcopyrite which were supplied by the ore fluid.

The mechanics of the process of transfer of the ore from a deeper source to its present position is a debatable question. Possibly it could have been brought up en masse with the intruding porphyry, but more likely it was injected from below as an ore magma during the final crystallizing stages of the deeper portions of the porphyry. Apparently it was trapped at the approximate position where the nearly vertical cylindrical body of porphyry, in its upward extension toward the surface, divides into a number of prongs or dikes.

Near Chuquicamata, Chile, there are four small

pegmatitic copper ore deposits consisting of coarse glassy quartz, orthoclase, mica, chalcopyrite, bornite and minor molybdenite. They are isolated occurrences in irregular dike-like bodies of granite-porphyry intruding granite. They show no genetic connection with fissures or brecciation. Just as in the case of the Colorada deposit, the facts of geology involved do not support a theory of introduction of the ores by hydrothermal solutions.

*Late-Magmatic Type. Ajo and Potrerillos:* The copper deposits of Ajo, Ariz., and Potrerillos, Chile, are of the late-magmatic type, and no doubt there are others. The author might designate these deposits more accurately as combination magmatic-hydrothermal, because both kinds of mineral deposition are present in each. They exhibit 1—an intrusion of what might be called a "porphyry" ore magma, and 2—a later addition of hydrothermal mineralization. They differ from the Morenci hydrothermal type of porphyry-copper inasmuch as in these two examples the porphyry-magma intrusion appears to have brought up with it a part of the copper which was later to be distributed during cooling and crystallization as disseminations, seams and veinlets of chalcopyrite and bornite throughout portions of the porphyry mass.

The intruded porphyry bodies are projections from deeper granite magmas, expelled at a time when higher portions of the magmas, possibly developing cupolas, had reached an intermediate stage in the processes of differentiation. Neither at Ajo nor at Potrerillos did these intruded fractions of the granite magma reach surface; they came to rest under a heavy covering, mostly volcanics at Ajo and a limestone series at Potrerillos. Both porphyry masses are roughly bulbous in form exhibiting greatly expanded upper parts but contracting downward to narrower bodies extending in depth no doubt to the parent granitic magmas.

Within these cooling masses of intruded magma, the greater portions of which have been eroded, mineralization from the crystallizing parent magma continued up to the time the porphyry masses were completely solidified. Geochemical processes through which the respective copper orebodies developed to the final stages were identical in the two deposits but less obscure at Potrerillos than at Ajo. At Potrerillos the primary copper minerals, chalcopyrite and bornite, with associated orthoclase and veinlets of quartz, are distributed throughout the porphyry but not uniformly. Limited portions are minable as ore. The quartz seams apparently represent the residual excess silica of the crystallizing magma, but they are not accompanied by any alteration of feldspar grains with which they are in contact. The introduced orthoclase, also of magmatic derivation, is pre-sulphide in time of crystallization and shows no alteration where in contact with the copper sulphides. There is relatively little pyrite, indicating that the sulphur content of the magma residue at the time of the porphyry intrusions was very small.

The late hydrothermal mineral additions to the easterly fringe of the Ajo orebody were derived from a late stage in the processes of differentiation in the underlying parent granitic magma, after sulphur had become an important constituent of the magmatic ore solution. At Potrerillos, the fissures acting as passageways for the late high-sulphur solutions depositing ore minerals, including enargite, covellite, pyrite and quartz, are well marked structural features, but at Ajo the fissure pattern through which hydrothermal solutions were introduced is not well defined.

An alternate to the theory of origin above set out may be suggested here, which is that the intrusion and final solidification of the porphyry was too early in the process of differentiation taking place in the granite magma to have brought with it more than insignificant quantities of copper. Under this premise, a fissure tapping the magma residue at a later but pre-hydrothermal stage of differentiation could have brought in the orthoclase-copper mineralization of the ore zone. Such an ore solution, low in sulphur, would probably have been alkaline in reaction. One objection to this hypothesis is the absence of fissuring at Ajo of the strength and type that would persist as ore channels to a deeper solution source. Furthermore, without some kind of a solution stoppage or cut-off effecting a time lapse, it seems difficult to explain the change from the orthoclase-copper mineral deposition requiring an alkaline feldspar-stable environment, to a high sulphur, hydrothermal type of mineralizing solution.

*Hydrothermal Type:* Butte has been cited as the classic example of this type. Among other well-known copper deposits belonging in this class are Morenci, Chino, Ely, Miami-Inspiration, Bingham, Bisbee, Magma, Cananea, and Chuquicamata. The members of this group of hydrothermal deposits resulted from definite orderly processes taking place in a crystallizing granite magma. This sequence of events in chronological order was:

1—Invasion of a granitic type of batholith.

2—Cooling and crystallization of the granite magma accompanied by processes of differentiation and "fractional crystallization."

3—Intrusion of a portion of the upper layer of the liquid granite magma into the already solid granite hood, and in some cases into the roof rocks.

4—Crustal fissuring tapping the magmatic solutions at their source.

5—Ore solutions ascending through fissures or other openings to deposit ores.

The copper deposits developed through the above series of events differ widely in their structural and geologic setting, as indeed they should in view of the variables involved, including composition and volume of the parent magma, its original metal content, and the numerous factors mentioned earlier. All of these variables shared to some extent in the final determination of the physical and mineralogical character of the deposit. It would be a miracle if two were found exactly alike. The remarkable thing about it is that they have enough features in common to enable us, with some confidence, to draw conclusions as to their origin.

It has already been noted that a single deposit, Potrerillos for example, may exhibit two types of mineral deposition, one involving a feldspar stable solution, the other a high sulphur hydrothermal solution; the former probably alkaline in reaction, the latter neutral or acid. The late-magmatic or *orthoclase* depositional phase is believed to be a near source phenomenon, in marked contrast to the far-from-source deposition of ore from hydrothermal solutions.

A logical conclusion is that one could expect to find a deposit of either type or a combination of the two. Chuquicamata, for example, shows both late-magmatic and hydrothermal phases of mineral deposition, but there the hydrothermal ores greatly

predominate, which is in reverse order, quantitatively, to that at Potrerillos.

Because of the fact, as proved at Butte, that the intense high-sulphur hydrothermal solution attack converts feldspars, including orthoclase, to sericite, the question is raised as to whether or not a late-magmatic orthoclase type of mineral deposition could have been present in certain copper deposits where we now see only evidence of intense hydrothermal activity in connection with the deposition of sulphide ores. Whether the hydrothermal solutions that eliminated the feldspars also effected a solution and re-deposition of an early copper sulphide minerals poses an interesting question.

At Butte, and most other hydrothermal-type copper deposits being considered, the intruding porphyry magma does not bring with it more than small traces of the metals of the ores; therefore it is required that the intrusion create a condition at its source favorable to the development and concentration of magmatic ore solutions which later ascend through fissures to form orebodies.

With reference to the problem of genesis, Butte has been selected for a more detailed analysis because of the extensive range of vertical and lateral mine developments open for examination and study, and because of the author's familiarity with geological conditions there. It will be impossible in the time allowed to describe in detail the other named deposits, or to make more than brief mention of the many interesting facts having to do with the genesis of the Butte ores. It should be noted here that my descriptions and considerations have reference only to primary or hypogene mineralization.

Butte is an area exhibiting extremely complex fissure systems of different ages, of which the two earliest, known as the East-West and Blue vein systems, are heavily mineralized, having produced very large tonnages of high-grade ores of copper, zinc and manganese. The deposition of copper ores consisting of chalcocite, enargite, bornite and chalcopyrite was accompanied by intense sericitic alteration of the wallrock. The ores of copper, zinc and manganese are zonally distributed in the order named, outward and upward from zones of highest alteration intensity. Four quartz-porphyry dikes of pre-vein age traverse the central and eastern portions of the district which coincide, significantly, with the largest area of intense alteration.

Brief descriptions of the quartz-porphyry dikes, alteration zones, and composition of the mineralizing solutions seem necessary here as a preliminary to the consideration of the problem of ore genesis, because these are the only observable facts that throw light upon the nature, origin and composition of the ore solution at its source.

The quartz-porphyry occurs in dike form within the vertical range exposed for observation, with one exception. In the East Colusa mine area, the Modoc dike is changing to an irregular stock-like form in the deep mine levels. In east-west distribution, the area of most numerous dikes extends from the Mountain View to the Pittsmont mine area. This area may be regarded as the center of porphyry activity marking the approximate position of the underlying source magma, a geological feature to be given emphasis later. It is also true, district-wise, that the cross-sectional area of quartz-porphyry is increasing with depth. A structural relation of some significance between the porphyry dikes, pre-porphyry fissures, and the earliest veins should be noted. The structure patterns of the dikes and the early East-West veins are similar in the area of maximum porphyry activity. Both strike southeasterly and dip southerly in the Mt. View and Berkeley mines. Easterly from that area, the dikes and veins change to northeasterly strikes and northerly dips, indicating that the same stresses were operative before and after the intrusion of the porphyry. These pre-porphyry fissures may have been the trigger setting off the series of events culminating in the formation of the Butte deposits.

### Alteration

Butte orebodies were formed chiefly by metasomatic replacement of wall rocks. In order that the original fissures or the veins under construction could have continued to act as passageways for solution travel during the growth of the veins, it is required that the attacking solution dissolve and carry away replaced rock materials more rapidly by volume than the replacing vein minerals are being deposited. Otherwise, the conduit would become choked or dammed and solution travel stopped.

At all times during mineralizing periods, the sericite fronts were migrating outward from solution channelways with the highest rates of advance at deeper horizons, in conformity with the maximum of intensity and potency of the ore-bearing solutions. The horizontal cross-sectional area of sericitization, greatest at deep levels, was increasing at successively higher points of reference in vertical range as long as hydrothermal activity continued. In the case of the Central zone, sericitization of the granite between earliest veins was completed upward to and above the present erosion surface within fairly well-defined lateral limits. In surrounding areas, however, it was only within the veins and in their immediately adjacent wallrocks that sericitization extended as high as the present surface, the intervening granite at high levels being fresh or only slightly altered.

In the broad picture of alteration at Butte in deep mine levels outside the Central zone, sericitic alteration is most widespread where fissures are closely spaced. Upward from any of these outside localized areas where alteration is extensive, the change to fresh granite between veins is not sudden but gradual, and it is characterized by argillic alteration along joint planes, cracks, and weak shear zones, all with gradually decreasing intensity upward from the more highly altered area. In vertical thickness this zone of gradual change is extremely irregular. District-wise, then, wallrock alteration in all its phases of intensity must be viewed as having been migratory upward from deep horizons from the beginning.

### Composition and Origin of the Ore Solution

Upon the basis of minerals added to the fissures and wall rocks, the ascending ore solutions arriving at horizons of deepest mine levels must have contained principally sulphur, copper, zinc, lead, manganese, silica, arsenic, carbon dioxide and iron, with minor fluorine and boron. They carried also any alkali or base radicals leached from the wallrocks at lower horizons. Judging from alteration effects they were probably acid in reaction. In what chemical combinations these elements may have been held during upward travel is indeterminate.

The series of events occurring at Butte were: 1—cooling and crystallization of the quartz-monzonite magma, with concurrent development of

aplite and pegmatite dikes; 2—intrusion of "quartz-porphyry" dikes cutting the granite, aplite, and pegmatite dikes; 3—crustal fissuring of the granite and porphyry; and 4—ore solutions rising through the fissures from a deep magmatic source and depositing the ores.

The quartz-porphyry was intruded before the solid granite hood had reached a great thickness, and before the processes of differentiation and fractional crystallization had gone on long enough to effect much change in the composition of the granite magma beneath the solid hood. It is here postulated that the intruded porphyry was not expelled from a distinct and separate quartz-porphyry magma but instead was an injection of a portion of the granite magma. A porphyritic texture developed at near-surface horizons where we now see it owing to its having been thrust as dikes into a relatively cool crust. Significantly, in the East Colusa mine, as previously noted, the horizontal cross-sectional area of the porphyry is increasing rapidly with depth and changing in form from narrow dikes to a stock-like body that is irregular in outline.

The vitally important deduction made from a study of the behavior of the porphyry dikes of the Butte area, and applicable to other copper deposits related to porphyries, is that the upward invasion of a portion of the granite magma brought about the development of a *sub-hood* cupola projecting above the main body of the magma into the solid hood of the granite itself. This upward projecting liquid mass became a closed system at the moment the narrow dike extensions solidified in the upper cooler part of the granite hood. The lower cupola mass was encased in the lowest layers of the solid granite hood having temperatures not greatly below that of the underlying magma, and because of this fact, the magma occupying the cupola remained fluid as the zone of magma solidification, including the top and walls of the cupola, migrated downward. This cupola and its magma environment presented a very favorable locus for the collection and concentration of water, sulphur, and the metals of the ores, a theory advocated by B. S. Butler and W. H. Emmons for granite cupolas extending into roof rocks.

The effect of the porphyry dike intrusion at Butte was to modify internal cooling stresses within the solid hood of granite and to cause thinning and weakening of the granite above the cupola, thus preparing it for the later initiation and development of fractures of the early East-West vein system.

Through the processes of differentiation and fractional crystallization which continued in the granite magma beneath the cupola hood, there was eventually developed what has been referred to as an *aqueous magmatic residue*, by others called the *magma residuum*. In early stages it was composed of water, volatiles, with probably some sulphur and metals, and the materials which form orthoclase and mica. But in later stages with the feldspars and micas crystallized out, the residue became the ore solution consisting of water, silica, sulphur, carbonic acid, and the metals of the veins and ores, later tapped by East-West fissuring to begin the formation of orebodies in higher levels. As long as orthoclase was crystallizing out, the magmatic residue was undoubtedly alkalic in character and reaction. But at the same time the alkalies were crystallizing out forming feldspars, the magmatic residue was being further enriched in sulphur, water, chlorine, carbonic acid, and other acid-forming constituents, none of which combines with other elements to form rock minerals of the monzonite. It is reasonable to assume, therefore, that in a closed system with a decreasing ratio of alkalies to acid constituents the "residue" would eventually become neutral or possibly acid in character, and remain so unless and until something occurred to cause it to revert to alkalinity. In this situation the magma is supplying the alkali radicals to the crystal mesh at a more or less constant rate, but there is simultaneous loss of these alkalies because of their crystallization to form orthoclase.

It follows that the composition and nature of an intrusion of a portion of the magma, or of an ore solution tapped from an aqueous magma, would depend upon the timing of the fracturing in relation to the stage of the "residue" development. At Butte the East-West fissures did not appear until relatively late in the process when the solutions were rich in water and sulphur, together with copper, arsenic, and other metallic elements now present in the Butte veins. It is believed that this late magmatic residue, or ore solution, was being held largely in what Gilluly terms "the crystal mesh", a zone of crystallizing magma topped by the hood and supported below by liquid magma. This in effect means that the "ore solution" was in part interstitial material dispersed generally in a large volume of formed or partly formed crystals.

The underground observed facts in Butte support this idea inasmuch as the period required for the build-up of the large orebodies common to the early East-West veins and their accompanying zones of alteration must have been a relatively long one. There can be little doubt, however, that the rate of upward flow of the ore fluids in the tapping fissures was affected adversely by the hydrostatic head and frictional resistance against which they had to move. Because of this it is not improbable that if the ore carrier was a liquid at the source before and at the moment of release, and at a temperature below the critical point, it would remain liquid after release into fissures. And it is also a reasonable deduction that in its journey upward against continuing pressure and decreasing temperature, a balance would be maintained keeping the ore fluid to and through the zone of ore deposition. This possibility was expressed by Ross in 1928:

> If it (the solution) escapes at high temperatures to a region of low pressure it will undoubtedly change to a gas phase, and its further reactions will be of the gas phase type. If, on the other hand, it is under sufficient pressure and escapes slowly through sufficiently tight channels, pressure may be maintained, and the water-rich, vein-forming materials may remain in the liquid phase throughout their mineralizing career.

### Mineralization Periods

The successive periods of mineralization at Butte present an interesting problem. The question arises: What are the underlying causes? Are they due merely to a succession of time-spaced fractures tapping a continuous flow of "magma ore solution" from its place of origin? Or, was there an actual cessation of mineral solution flow over a substantial period of time, afterward rejuvenated by the tapping of a continuing accumulation of solutions by fissures definitely later in age than the earliest known fis-

sures of the East-West system? The following facts have a bearing on these questions.

At all levels the East-West veins are vuggy and they are enclosed in altered rock. When first opened by mine workings a heavy flow of water shows both the veins and altered rock to be excellent water channels. This fact demonstrates beyond question that ore solution travel through these early veins did not stop because of plugging. The cause must have been deep-seated.

A time lapse between the close of East-West mineralization activity and the beginning of Blue Vein ore deposition is indicated by differences in mineral composition of the two vein systems. The early veins are very quartzy, with high proportions of zinc, manganese and enargite, in strong contrast to the ores of the Blue veins which are low in zinc and manganese, with much less enargite in proportion to chalcocite and bornite.

There is always the question as to how much of the mineralization of the earlier veins was added during the Blue Vein mineralizing activity. There is abundant proof at intersections in higher levels that the East-West veins had grown to their full widths, and they show no enrichment at Blue Vein intersections. However, at deeper levels enrichment of East-West veins at crossings by Blue fractures is common, which is as it should be because the vertical range of mineral deposition had moved considerably lower prior to and during the span of Blue Vein activity.

The tops or upper limits of Blue Vein copper ore shoots are universally at lower elevations than those of the East-West veins by as much as 500 to 1500 ft. Such a marked difference would have been unlikely under a condition of sustained flow of mineralizing solutions from a common source. This difference in upper limits of mineral deposition in the two vein systems is indicative of a downward migration of the solution source, resulting in a downward shift of the whole vertical range of deposition during the time lapse between the East-West and Blue Vein periods of mineralization.

The cause of solution stoppage and subsequent renewal of activity poses an interesting but difficult problem, for the explanation of which the author has only a suggestion. It may have been caused by draining, through the East-West fissures, of the long accumulating reservoir of magmatic ore solution at a much more rapid rate than it was being supplied from the crystallizing magma. Under the hypothesis that the "ore solution" had become neutral or "acid" in final stages of accumulation, the effect of complete draining would be to restore the "magma residue" to a condition of feldspar stability, and this with decreasing pressure might cause crystallization of the granite minerals to continue to a point where the system again became a closed one. The processes of fractional crystallization, with its resulting magma residue, or "magmatic ore solution" accumulating within the *crystal mesh* beneath the newly formed solid cupola hood, would then continue at this deeper horizon just as it did at higher levels prior to tapping by the East-West fracturing, and without essential change in chemical composition.

The advent of Blue Vein fissures ended this period of ore solution inactivity. This fissuring resulted from changing stresses brought about by East-West fractures and the lessening of compressive strength of the intensely altered block of granite and porphyry, oblong in horizontal section and plan, reaching from the lower limits of East-West fissure penetration to the surface. Because of the increasing cross-sectional area of altered rock at successively lower horizons the Blue fissuring was centered over this roughly cone-shaped altered rock mass, and hence involved a much smaller area at and near the surface than was included in the earlier East-West area of fissuring. The Blue fracturing broke down through the newly formed barrier into the crystal mesh as far as fissurable and into the source of the newly generated ore solution.

The No. 16 vein, a northeast striking mineralized fault, closely followed the Blue veins in time, but all later faults, including the Rarus and Middle, either did not tap an ore solution source, or the source had receded to so great a depth that the deposited ores do not reach as high as deepest existing mine workings.

### The Roles of Sulphur Silica and Water

Comparisons of certain characteristics of the Butte and Potrerillos types of copper deposits might be of interest. The Butte ores exhibit high sulphur, and much additional sulphur occurs as disseminated pyrite in the intense sericitic alteration zones encasing the ores, but orthoclase is absent as a vein mineral. The Potrerillos and Ajo deposits, omitting hydrothermal ore additions, show low pyrite, low sulphur, and very weak alteration of plagioclase feldspars, but large amounts of fresh orthoclase as a product of mineralizing activity. The primary copper minerals at Butte are chalcocite, bornite, enargite, digenite, covellite and chalcopyrite; at Ajo and Potrerillos they are chalcopyrite and bornite only. The absence of orthoclase mineralization is characteristic not only of Butte but of all high sulphur hydrothermal mineralizing activity in the porphyry coppers. The Butte zone of ore deposition is thought to be relatively far from the solution source, while the Potrerillos-Ajo type of orthoclase-copper mineral complex is believed to be a near source deposition. These facts are highly revealing as indicating, if not demonstrating, the tremendously important role played by sulphur in the processes through which the nature of an ore solution is determined at its magma source.

Sulphur, silica, and water are unquestionably the most effective agents of hydrothermal ore accumulation. Sulphur does not unite with silica to form rock minerals, but it readily forms compounds with iron and nonferrous metals common to ore deposits. As pointed out by H. D. B. Wilson in his interesting paper, Vogt's data on sulphide solubility indicate that 0.2 to 0.4 pct of sulphur can be dissolved in a basic magma, but sulphur is held only sparingly in magmas containing more than 55 pct silica. However, one of the most important questions relates to its disposal or distribution during solidification of the magma. It is highly probable that in the absence of water, sulphur combines with any copper, nickel, or excess iron present, to form an immiscible sulphide melt. During crystallization of the rock silicates the sulphide melt particles dispose themselves throughout the rock as disseminations, or they may sink and collect to form massive orebodies.

Under the foregoing premise it is apparent that a high-sulphur hydrothermal ore solution does not develop from a magma which crystallizes to form a basic rock, one of the reasons being that the basic

silicate minerals in such rocks are not carriers of free water and no other source is provided. It is known, however, that hydrothermal ore solutions are developed in granites, porphyries, and acid volcanic rocks, all having abundant free quartz as a rock mineral. Is it not reasonable then to look to a silica-rich magma as the most likely source of water at the critical moment of crystallization of the silica as quartz, for the creation of a hydrothermal ore solution, or the "magmatic ore solution" of Bowen and Ross?

Quartz was the last mineral to crystallize in the cooling phase of the quartz-monzonite at Butte. The question is: What was the physical and chemical make-up of the silica just prior to its crystallization as quartz? It could not have been pure liquid silica at the temperature of fluid granite, which many agree is several hundred degrees below the melting point of pure silica. It must have been something in the nature of a chemical compound, or physical combination of silica and water. Therefore, it is here suggested that at the moment of solidification as quartz the water was expelled to join the magma ore solution in its critical role as the carrier of the sulphur and other materials composing the magma residue.

At Sudbury a controversy of long standing had arisen between those supporting the theory that the massive sulphide bodies are accumulations of "magmatic" sulphides that have segregated immiscibly out of the basic norite magma and those advocating deposition of the ores from hydrothermal solutions derived from a magma source. Yates brings out the fact that two types of igneous rock are involved, the norite and a quartz-diorite. Is it not logical to conclude that both types of orebody could have developed: massive sulphides from the basic low-silica norite magma and hydrothermal ores along fissures from the high-silica quartz-diorite? The Mouat nickel-copper deposits in Stillwater County, Mont., associated with basic intrusives and granite, exhibit isolated copper-nickel sulphide masses in the basic rocks not related to fissuring, and a fissure vein containing lenses of sulphides similar in mineral composition to the massive sulphide bodies.

Summarizing, the author believes there is a series of events, fundamental in nature, that are essential to the build-up of copper deposits related to porphyries. These are: 1—a granitic batholith invasion of the earth's crust; 2—cooling of the batholith accompanied by processes of "differentiation and fractional crystallization" within the magma; 3—intrusion of a portion of the fluid magma upward into the earlier crystallized granite hood or into roof rocks, forming a localized sub-hood cupola; 4—crustal fissuring tapping the "magmatic residue", or "ore solution" developed within the cupola; and 5—formation of orebodies in association with the fissures.

The resulting type of deposit will depend primarily upon:

(a) timing of the "sub-hood" intrusion with respect to the stage of differentiation reached in the crystallizing magma below the granite hood;

(b) timing of the crustal fissuring which taps the "magma residue" accumulating in the sub-hood cupola; an early release producing mineralization of the orthoclase-copper type; a late release producing the high-sulphur hydrothermal types.

The "porphyry" and related copper deposits thus seem to be products of plutonic magmas containing excess silica. The more acidic, that is, the greater the excess of silica in a magma, the more water it will hold. Therefore, a granitic or quartz-monzonite magma should prove to be a favorable medium for supplying, during crystallization, water, sulphur and silica, the three substances essential to the accumulation of a magmatic ore solution.

At the beginning it was stated that a better understanding of the genesis of ore deposits is highly desirable as an aid to the maintenance of the nation's reserves of natural resources. Let it be suggested here, in connection with future laboratory research programs designed to add to existing knowledge of the genesis of sulphide deposits, that most serious attention and study be given, supplemented by experimental work, to the vital roles played by sulphur, silica, and water, in the development of ore solutions from magmas and in the distribution of ore minerals in zones of ore deposition.

# Exploration of the Oaxaca Coal Fields In Southern Mexico

by Luis Toron and Salvador Cortes-Obregon

THE Oaxaca coal fields, shown in Fig. 1, are located in the Alta Mixteca region in the states of Oaxaca, Puebla, and Guerrero. Known outcrops are scattered over 3125 square miles. It is probable that further exploration will reveal a more extensive area of deposits.

The region is of great importance to Mexico, as at present the only sources of coal are the fields near the U. S. border. Steel mills are also located in the North, and finished products must travel 600 to 800 miles to the area of consumption in central Mexico. The Oaxaca coal, only 120 miles south of Mexico, D.F., lies close to several iron ore deposits. If this

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Fig. 1—On the above map of Mexico state boundaries are indicated by broken lines and railroads by solid lines. Locations of iron ore deposits are marked by heavy crosses, steel mills by triangles, and coal deposits by shaded areas.

coal can be used in steel production is will be possible for the Mexican steel industry to reach new dimensions, commensurate with the growing industry of the central region. Coal can be utilized in thermoelectric plants in this area, which lacks not only petroleum and natural gas but also electric power. It can be used as domestic fuel, replacing charcoal and firewood.

In March 1910 J. L. W. Birkinbine presented the results of his exploratory work in the coal region of Oaxaca.[1] His data were encouraging, but other workers[2-4] disagreed as to the value of the deposits. Studies were abandoned until 1949, when the present writers were assigned to evaluate the reserves and determine ways they might be utilized best.

Complete study of an area this size would cover a long period of time and would require the services of a great many specialists who are not available. For this reason it was decided, after initial reconnaissance, to concentrate on a zone with a large number of deposits close to existing communication facilities and to investigate the remaining area in the future. The selected portion of 120,000 acres is divided into two parts, the Tezoatlan-Consuelo area shown on the map and in cross-section, Figs. 2 and 3, and the Mixtepec area 30 miles farther south.

The study has been systematic, starting with detailed topographic and geologic mapping, followed by trenching in all the outcrops encountered. To determine continuity of the coal, samples were first taken in trenches, following procedures recommended by the U. S. Bureau of Mines. These samples gave results which vary considerably from samples of fresh coal taken from underground workings. At 15 strategic places along the outcrops drifts were driven 80 to 100 ft; samples were taken at points of farthest advance.

Table I shows analyses of 11 samples, selected for illustration from 250 samples taken on the outcrops.

Table I. Analyses of Samples Taken In Exploration of Outcrops[a]

| Sample No. | Thickness Sampled, Meters | Dry Basis | | | | |
|---|---|---|---|---|---|---|
| | | Volatile Matter, Pct | Fixed Carbon, Pct | Ash, Pct | Calorific Value, Btu | Sulphur, Pct |
| 66 | 1.00 | 19.50 | 26.26 | 54.25 | 4509 | 0.26 |
| 111 | 1.60 | 23.75 | 40.42 | 35.83 | | |
| 113 | 0.70 | 19.97 | 45.35 | 34.68 | 7694 | 0.49 |
| 77 | 0.48 | 21.80 | 49.34 | 28.86 | | |
| 3 | 2.20 | 17.82 | 48.44 | 33.74 | 8213 | 0.40 |
| 4 | 1.47 | 17.92 | 53.28 | 28.80 | 9120 | 0.43 |
| 213 | 1.48 | 13.78 | 47.57 | 38.65 | 7909 | 0.41 |
| 229 | 1.19 | 12.43 | 55.49 | 32.08 | 9311 | 0.47 |
| 14 | 1.42 | 7.63 | 43.25 | 49.11 | 7146 | 0.77 |
| 27 | 1.52 | 16.76 | 44.41 | 38.83 | 8523 | 0.64 |
| 42 | 3.70 | 18.45 | 46.40 | 35.15 | 8747 | 0.64 |

Ash content varies from 26 to 55 pct and heat value from 4500 to 9300 Btu. Table II gives results from two fresh coal samples, analyzed at the U. S. Bureau

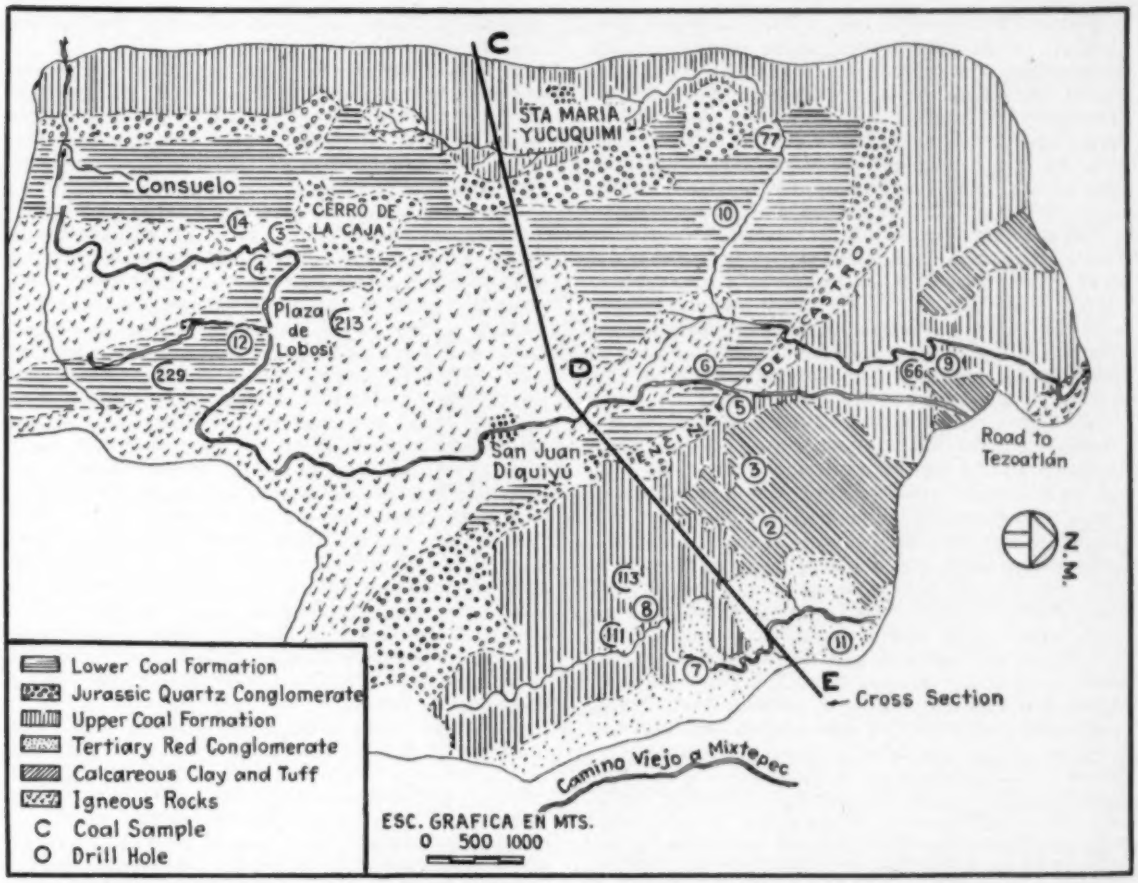


Fig. 2—Geologic map of the Tezoatlan-Consuelo area, Oaxaca. The Mixtepec area lies 30 miles farther south. The two regions make up the 120,000 acres selected for study.

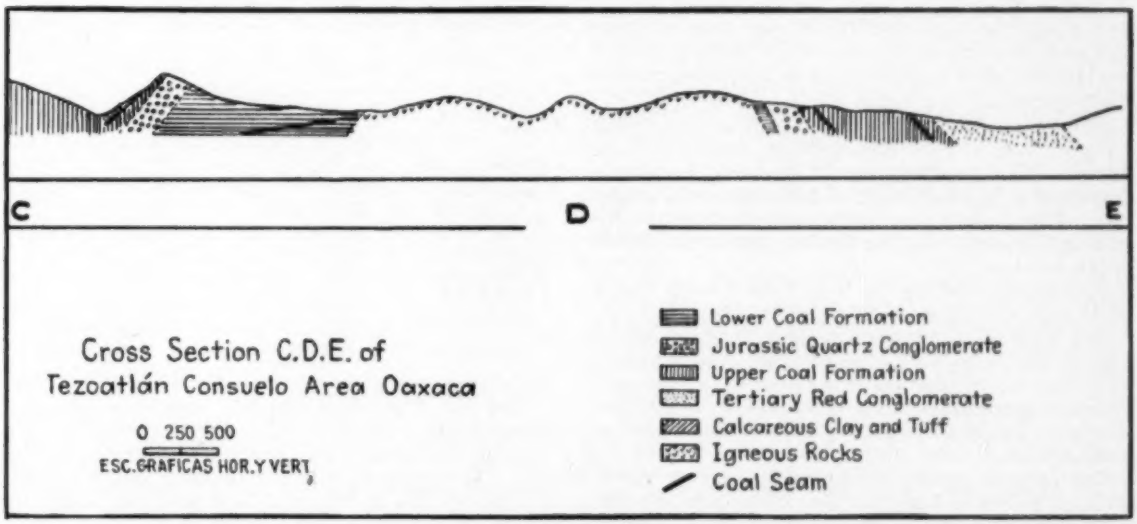


Fig. 3—In the Tezoatlan-Consuelo area, which received concentrated study, the stratigraphy is as follows: gneiss and schists; Triassic-Jurassic sediments, terrestrial, marine or lacustrine deposits, in which the coal is found; Cretaceous limestones; and finally Tertiary basalts and red conglomerates and andesite and rhyolite lavas and tuffs.

of Mines, which are typical of the two qualities of coal encountered in the 15 exploratory drifts. Ash content is 23 to 30 pct and the heat value, about 11,000 Btu, is much higher than that given in Table I.

The drilling program started in 1951 is continued today. Two 22 HD Joy rigs are being used, drilling 1100 ft with NX bit and 2500 ft with BX bit. Table III summarizes results of the drilling.

Simultaneously with the drilling program preliminary studies have been made on the quality, preparation, and utilization of the coal. At the Instituto Mexicano de Investigaciones Tecnológicas laboratory in Mexico, D.F., float-and-sink laboratory tests have been made, as well as carbonization tests on small samples. Other samples have been sent to the laboratory of Preparation Industrielle des Combustibles in France for similar analyses.

The area under study lies in the Sierra Madre del Sur, and its main surface characteristic is the great local relief, the elevations varying from 4500 to 7500 ft above sea level. The higher mountains have a sharp form and other secondary elevations a rounded shape due to stronger erosion. Mesas of great extent and almost flat summits remain as evidence of important lava flows.

The hydrographic system of the area is also complicated. During the rainy season numerous gorges discharge their currents into tributaries of the Balsas River, largest river on the west Mexican coast.

It is easy to understand that when this work was started, it was difficult to reach the areas under investigation. Long and tiresome rides on horseback were necessary to travel the region and to make the first reconnaissances. The Tezoatlan-Consuelo area is 15 miles south of Huajuapan, a village on the Pan-American highway, and the Mixtepec area 45 miles south of the village. From the Pan-American highway a primitive system of automobile roads has been developed, and it is now easy to reach all the workings by car and also to move the rigs to projected drill-hole locations. A station on the narrow-gage railroad is located on the Pan-American highway 100 miles north of Huajuapan. A standard-gage railroad crosses the highway 100 miles to the southeast of Huajuapan.

From the base upward,[4] stratigraphy of the zone is as follows: gneiss and schists; Triassic-Jurassic sediments, terrestrial, marine, or lacustrine deposits in which the coal is found; Cretaceous limestones; and finally Tertiary basalts and red conglomerates and andesite and rhyolite lavas and tuffs, see Fig. 3. In the Mixtepec zone there are also granitic and dioritic rocks.

The older Jurassic sediments are of the Lower Jurassic and can be identified by a rich flora of cycads that appears in several horizons, previously described,[7-9] which have provided a base for correlation. There are also well-preserved fossils of bivalves (Trigonia, Venus, Ostrea) and some genera of ammonites.

The Jurassic sediments, where the coal is found, have been sub-divided into three formations:

The lower coal formation, 1000 ft thick, is present only in the Tezoatlan-Consuelo area. It is composed of lutites, shales, and slates with layers of coal and carbonaceous shales, sandstones, and a dark brown conglomerate of limestone boulders held in a clayey cement.

The Jurassic quartz conglomerate, 150 to 300 ft thick, is found in both the Tezoatlan-Consuelo and Mixtepec areas. It is composed of some beds of quartzite intercalated with conglomerates of angular white quartz (also gneiss and schist fragments) cemented with a very hard siliceous material of red to yellow-brown color.

The upper coal formation, present in the Tezoatlan-Consuelo and Mixtepec areas, is over 1500 ft thick. It is composed of sandstones; mudstones and sandy shales with layers of coal and carbonaceous sandstones; slate; and thin layers of argillaceous limestone.

It should be pointed out that there are stratigraphic gaps in the area. The Upper Jurassic has not been identified, and limestone of Lower Cretaceous age has been found only in some marginal zones. It is not possible to state whether these stratigraphic gaps are due to interruptions in sedimentation or to intensive erosion of the post-Lower Jurassic sediments. On the other hand, a great part of the areas studied is covered by the Huajuapan formation, an interesting Tertiary formation[9] composed of a reddish coarse-grained conglomerate containing mainly limestone boulders, two thick basaltic lava flows, and a succession of sandstones and tuffs. This formation, partly eroded, covers the coal formations unconformably, as has been confirmed by the drill holes, and does not reveal the true extent of the coal formations or the possibility of a complete stratigraphic column at some place beneath the Huajuapan formation. Continuation of the drilling will solve these questions and others.

There are two workable seams in the lower coal formation with a thickness of 5 to 7 ft each, but in some sections only one of the seams has been found. The upper coal formation has two zones with workable coal. In each zone there are three seams, 5 to 7 ft thick, appearing in some places as two seams or as a single seam 10 ft thick or more, the others being absent or very thin.

The areas show considerable folding and some faults. It is difficult to establish a pattern that can be applied in detail to the strikes of the axes of the main synclines or anticlines. The tops of the anticlines have been eroded and the sedimentary formations can be seen only in places where the synclines have not been covered by younger rocks, mainly volcanics.

Table II. Analyses of Samples Taken In Small Mines Over 60 Feet From The Outcrop[6]

| Item | D-87371 Lower Formation Zone of Tezoatlan | | D-87370 Upper Formation Mixtepec Zone | |
|---|---|---|---|---|
| | As-received | Free from Moisture and Ash | As-received | Free from Moisture and Ash |
| Moisture | 9 | | 1.0 | |
| Volatile matter | 9.1 | 12.0 | 17.4 | 25.4 |
| Fixed carbon | 66.6 | 88.0 | 51.1 | 74.6 |
| Ash | 23.4 | | 30.5 | |
| Hydrogen | 3.4 | 4.3 | 3.8 | 5.3 |
| Carbon | 68.3 | 90.2 | 59.0 | 86.0 |
| Nitrogen | 0.7 | 0.9 | 1.0 | 1.4 |
| Oxygen | 3.6 | 3.8 | 4.9 | 6.2 |
| Sulphur as: | 0.6 | 0.8 | 0.8 | 1.1 |
| Sulphates | 0.02 | 0.02 | 0.03 | 0.05 |
| Pyritic | 0.13 | 0.17 | 0.23 | 0.33 |
| Organic | 0.43 | 0.57 | 0.51 | 0.74 |
| Btu | 11560 | 15270 | 10430 | 15220 |
| | Free swelling: non-coking | | Free swelling index: 5 | |

The dip of the coals seams is variable, in general from 10° to 30°, with a tendency toward flatter dips at depth; in some places the seams dip from 30° to 50°. Consequently different types of mines can be predicted: almost flat mines and mines of moderate to strong inclination, with entrances by drift or by shaft. From the general information on small prospecting mines it has been found that the coal seam has one or two bands of bone which can be easily separated when the mine is worked. The roof is good and is expected not to present any problem.

Because the coal has a high ash content, as shown in Table II, some workers have called it black shale.[4, 6] The ash is finely and intimately distributed,

## Table III. Data on Vertical Drill Holes

| Hole No. | | Coal Seams | | | | | Metamorphic Rock* | Bottom |
|---|---|---|---|---|---|---|---|---|
| 1 | From | 55.33 | 65.08 | 70.00 | 240.28 | 324.96 | | |
| | to | 57.26 | 67.00 | 70.86 | 242.50 | 325.96 | | 369.72 |
| | Thickness | 1.53 | 1.92 | 0.86 | 2.22 | 1.00 | | |
| 2 | From | 245.82 | 274.10 | 293.99 | 298.61 | 300.48 | | |
| | to | 246.48 | 275.87 | 294.84 | 299.66 | 301.85 | | 340.15 |
| | Thickness | 0.66 | 1.77 | 0.85 | 1.05 | 1.37 | | |
| 3** | From | | | | | | | |
| | to | | No coal | | | | | 270.97 |
| | Thickness | | | | | | | |
| 5† | From | | | | | | 86.25 | |
| | to | | No coal | | | | 116.44 | 116.44 |
| | Thickness | | | | | | | |
| 6† | From | | | | | | 2.75 | |
| | to | | No coal | | | | 295.14 | 295.14 |
| | Thickness | | | | | | | |
| 7 | From | 110.66 | 130.80 | 173.12 | 179.51 | 194.51 | 260.85 | |
| | to | 112.03 | 131.77 | 174.03 | 182.06 | 196.29 | 265.79 | |
| | Thickness | 1.37 | 0.97 | 0.91 | 2.55 | 1.79 | | 265.79 |
| 8 | From | 63.87 | 85.62 | 87.60 | | | 158.40 | |
| | to | 65.12 | 87.22 | 88.89 | | | 214.59 | 214.59 |
| | Thickness | 1.25 | 1.60 | 1.29 | | | | |
| 9‡ | From | 99.02 | 169.51 | | | | | |
| | to | 99.78 | 171.41 | | | | | 179.31 |
| | Thickness | 0.76 | 1.90 | | | | | |
| 10 | From | 28.04 | 119.31 | | | | 130.35 | |
| | to | 28.75 | 120.56 | | | | 192.12 | 192.12 |
| | Thickness | 0.71 | 1.25 | | | | | |
| 11§ | From | | | | | | | |
| | to | | No coal | | | | | 251.77 |
| | Thickness | | | | | | | |
| 12§§ | From | 23.57 | 26.94 | | | | 64.41 | |
| | to | 24.54 | 28.46 | | | | 87.56 | 87.56 |
| | Thickness | 1.07 | 1.52 | | | | | |

* An igneous metamorphic rock (basalt and andesite metamorphized).
** On a squeeze zone; no coal.
† To explore metamorphic zone; no coal.
‡ Continuance of drilling impossible because of bad ground.
§ Before coal seams were reached, continuance of drilling impossible because of bad ground.
§§ Horizontal strata.
All measurements are in meters. Thickness is measured along the drill and dip varies between 12° and 20°. Only seams thicker than 2 ft are tabulated.
No. 4 hole not finished at time of writing. Holes 5, 6, 10, and 12 are on the lower coal formation; the others are on the upper coal formation.

however, and the authors' own preliminary experiments carried out in the laboratory of Instituto Mexicano de Investigaciones Tecnológicas have proved that the coal can be washed in small sizes, —4 mesh. The tests made in France by Preparation Industrielle des Combustibles, a firm specializing in preparation of high-ash coal, have confirmed the results of the authors' experiments. The combined results of the testing programs have led to the following conclusions.

1—The coal from the lower coal formation is semi-anthracite, whereas coal from the upper formation is medium-volatile bituminous coal and shows considerable differences in the two areas studied. The coal from Mixtepec has good agglutinating properties and is suitable for the production of metallurgical coke. Coal from the Tezoatlan-Consuelo area, despite the fact that the seams have been correlated with the Mixtepec seams, does not have any caking property, possibly because of the closer presence of igneous rocks.

2—The fines can be washed by froth flotation. A product of 12 to 15 pct ash content has been obtained with 80 pct recovery.

3—The —½ in. coal has given a product of 12 to 15 pct ash content with 65 pct recovery.

4—No efficient cleaning can be expected with sizes larger than ½ in.

5—Because of the high quality of Mexican iron ores, the steel industry of the country can use coke with higher ash content than usual in other countries.

6—The high ash semi-anthracitic coal (23.4 pct ash and 11,560 Btu, as received) can be burned without washing.

7—Laboratory tests must be confirmed by large-scale tests.

At the present time, surface work and the drilling program under progress have confirmed a reserve of 100 million tons of coal. Mexico produces slightly more than a million tons of coal annually. Since the Oaxaca coal is of great importance to Mexico, it is necessary to continue the exploratory work to increase the reserves, and to investigate thoroughly the mining possibilities and the preparation and utilization of the coal.

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# Block Caving Practice At The Jeffrey Mine

**Large-scale caving operations in the asbestos orebody of the Jeffrey mine present problems in undercutting and slusher drift development. The solution of these problems and the development of aluminum forms for concreting slusher drifts are detailed in this three-part article.**

BLOCK CAVING HAS BEEN DEVELOPED to a high degree of efficiency in the last two decades and more particularly since World War II. At the Jeffrey mine of Canadian Johns-Manville Co., in the Eastern Townships of Quebec, several innovations have increased production and decreased costs. Asbestos ore is produced at the rate of 10,000 tpd from an underground operation supplemented by a large open pit that has been mined since 1881.

The orebody consists of asbestos veins in a fractured and serpentinized peridotite. Hardness and structural strength of rock vary from soft shear zones at one extreme to a small amount of hard granitic inclusions at the other. In general the ore is weak and deteriorates on exposure to air, so that it is difficult to maintain underground openings for any period of time. Permanent workings are lined with concrete and temporary ones are driven minimum size and supported with steel sets as required.

The caving unit is a block 200 ft square, served by slusher drifts driven north and south halfway across the block from the haulage drifts. The average block is over 400 ft high and contains approximately 1.5 million tons. Caving is induced by mining out a horizontal slice above slusher drift points and across the bottom of the block. The units are prepared for undercutting as a number of small independent units which are grouped for simultaneous blasting to minimize effect of local ground failure in weak rock.

Aluminum forms are used for concreting slusher drifts, haulage drifts, and shafts, and advantages of speed in handling and safety due to their light weight promise to result in still wider application.

## Part I

# Slusher Drift Development

by H. H. Waller

ORIGINALLY slusher drift development was conventional, advancing the drift full 10x13-ft size at 6 ft per round. This proved dangerous and costly because the weak fractured rock of the orebody cannot be left raw for any length of time without its reacting with air to cause spalling. With this method of drift development ground conditions were worsened by many blasts and the length of time it was necessary for the drift to remain open.

The problem was practically solved by driving 5x7-ft pilot drifts, then enlarging to 10x13-ft raw size by slashing with 50 to 60-ft diamond drill holes. Calculated explosive charges are used to avoid wall and roof shattering. Still more recently jacklegs and sectional steel replaced the diamond drills, resulting in the same work for less than half the cost, see Figs. 1 and 2.

Crosscuts at right angles to the main haulage drifts, which cross through the center of the orebody, divide the ore into 200-ft blocks. Eight slusher drifts on 50-ft centers draw from one block. The slusher floor is 11 ft above the rail, inclined at 1 pct grade, and the top is 18 ft below the undercut. The finished slusher drift is 102.5 or 120 ft long, depending on whether it is north or south of the crosscut. Drawpoints are staggered on each side at 17.5-ft centers. The completed drift is concreted and has an inclined ramp and a vent at the back.

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When crosscuts and gangways have been excavated and concreted and slusher stations installed, slusher drift development is carried out in 10 clear-cut stages: 1—Pilot drift is driven full length, 5x7 ft. 2—Station is excavated at half-way point in pilot drift. 3—Pilot drift is enlarged to slusher drift size by drilling. 4—Lower part of slash is blasted and mucked for floor concrete. 5—Floor is poured. 6—Inside upper half of slusher drift is blasted, mucked, and concreted. 7—Outside upper half of slusher drift is blasted, mucked, and concreted. 8—Drawpoints are excavated. 9—Drawpoints are concreted. 10—Concrete ramp and sheave protection recess are constructed at back end of slusher drift.

A 5x7-ft pilot drift is driven full length on the center line of the proposed slusher drift using a jackleg and detachable bits on ⅞-in. hexagon steel. A 10-hp air-driven slusher and 36-in. scraper pull muck directly into cars in the main haulage crosscut, see Fig. 2. Operations are on a three-shift basis. One man mucks the previous round, drills, and blasts his round in a shift. Average advance is 5 ft per shift.

When the pilot drift is completed, 7 ft of drift in the center section is enlarged to full raw slusher drift size of 10x13 ft, for the set-up to drill long slash holes.

The pilot drift is slashed to full raw size from this station with jacklegs and tungsten carbide chisel bits on ⅞-in. sectional steel. Crews line the holes without trouble, working from controls established by the engineers, and the pattern of holes for the slash is arranged to give the least shattering effect

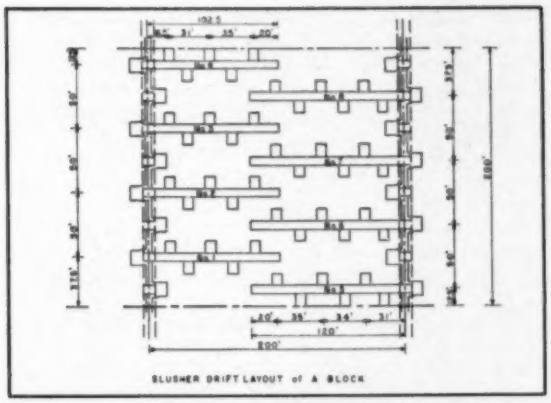



Fig. 1—Crosscuts divide orebody into 200-ft blocks, and eight slusher drifts on 50-ft centers draw from each block.

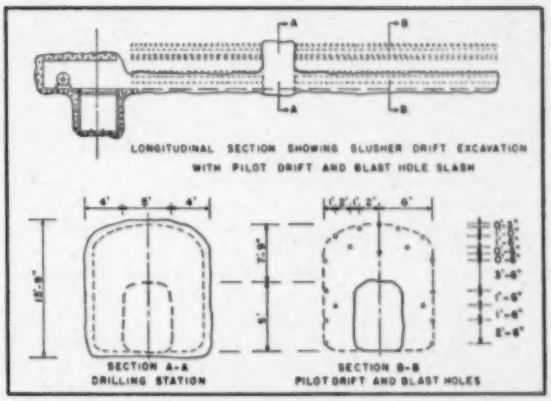

LONGITUDINAL SECTION SHOWING SLUSHER DRIFT EXCAVATION
WITH PILOT DRIFT AND BLAST HOLE SLASH
SECTION A-A
DRILLING STATION
SECTION B-B
PILOT DRIFT AND BLAST HOLES

Fig. 2—Sections show how long holes are used to slash 5x7-ft pilot drift to 10x13-ft raw slusher drift size.

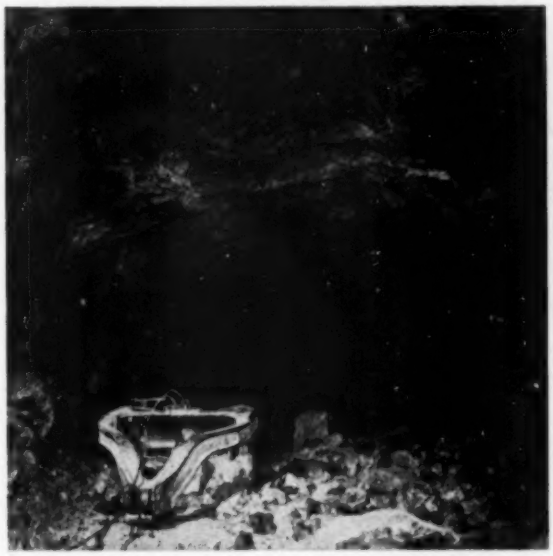


Fig. 3—Concrete floor can be seen in view of slusher drift taken after blasting of upper half.

Fig. 4—In this photograph the aluminum forms are in place to concrete half the drift.

on the walls and roof from blasting. Two-man crews drill the 50 to 60-ft holes on line averaging 125 ft per man shift.

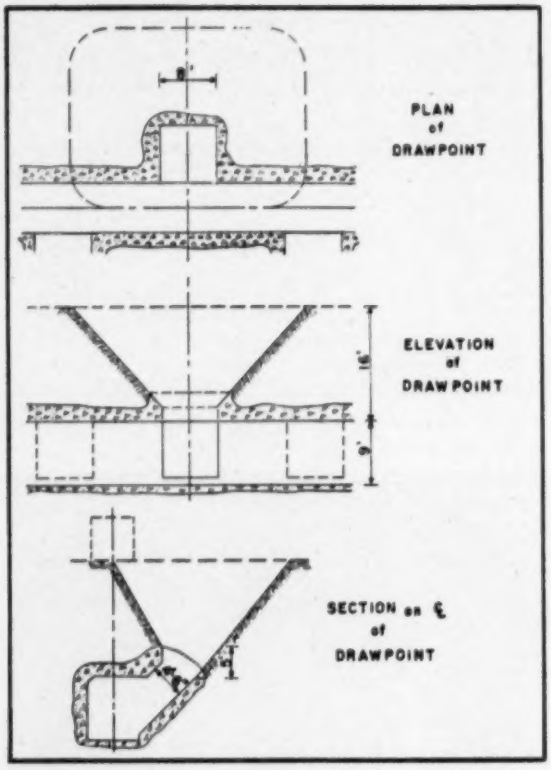
After drilling is finished, millisecond delay caps are used to blast the lower one-third full length. The slash is mucked directly into 10-ton tipple cars with a 42-in. scraper and a 15-hp air-driven slusher.

This excavation having been completed, a concrete floor 1 ft thick is poured the full length of the slusher drift. In the first 20 ft, 65-lb rail is placed in the concrete for wear protection. This concreting is done before the rest of the slash is blasted, because it is more economical to scrape the rest of the muck on a smooth floor, and the excavation provides the space required for blasting the remainder of the slash.

When the concrete floor is sufficiently cured, the upper part of the slash is blasted. Care must be taken with blasting, so millisecond delay detonators are used. Rotation prescribed by textbook is strictly followed to avoid any undue shattering of walls or roof. With these precautions, additional work can be continued without timbering, and this method of blasting also gives a well fragmented pile which is easily mucked into cars, see Fig. 3.

Before any more blasting is done, this opening or portion of the slusher drift is concreted, with recesses left at intervals for construction of drawpoints. Because of the quantity, concrete is poured on a mass production basis. Aluminum forms are used (*see Part III*) and concrete is placed behind them with a pneumatic Press-Weld placer. Concrete of at least 4000 psi (after 28 days and without reinforcing) is desired. A minimum of 18 in. of concrete is used. Reinforcing is not used because there has been experience of blasting vibration breaking the bond with the concrete and causing lines of weakness.

After the concrete has been poured 24 hr the second or front upper half of the slash can be blasted. The same procedure takes place here as in the first half. But in this operation one handling of forms for concreting does two jobs, namely stripping from the first half and placing again for the pour in the second half. It should be mentioned here that aluminum forms for concreting are particularly well adapted to handling. They are far superior to steel forms because they are light. Wood, of course, is not used as it would contaminate the fibre. At this point there is a concreted slusher drift minus



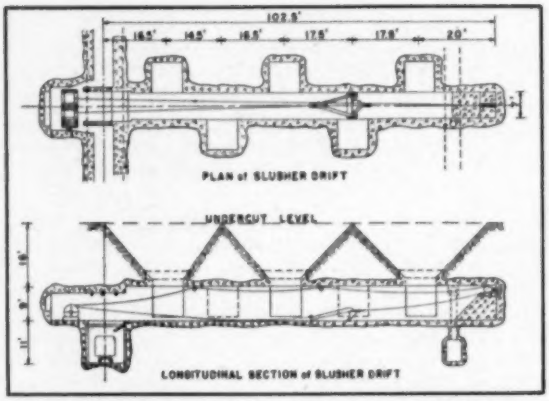




Fig. 5 (left)—Plan, elevation, and section of completed draw point. Fig. 6 (above)—Plan and section of completed slusher drift also shows ventilation arrangement located below drift.

the drawpoints, but with recesses for them, see Fig. 7. Fig. 4 shows aluminum forms in place for concreting.

The drawpoints are among the last steps of developing a slusher drift. Because of bad ground condition it is necessary to develop the slusher drifts in sections and, for the same reason, to excavate and concrete the drawpoints separately. The excavation is made high enough to allow for an opening 8 ft x 4 ft 6 in. when concreted and at least 5 ft long. The drawpoint floor, at 45°, enters the slusher drift wall 1 ft above the drift floor, Fig. 5. Broken rock is mucked with the regular production slushing unit, a 72-in. folding scraper and a 125-hp electric locomotive and 200 cu ft ore cars.

Concreting is done in much the same manner as in the slusher drift. The bolted aluminum forms are designed to allow the floor, walls, and brow to be poured in one operation. When using portable forms it is necessary to do a certain amount of bulkheading because it would be impossible to design a form to fit any rough wall, see Fig. 11, Part II.

The last part of the construction is a ramp to prevent the back end of the slusher drift from filling with muck which the scraper pulls back . The steel-faced concrete ramp at 45° slope extends to within 2 ft of the back end of the slusher drift and far enough ahead to allow a recess for sheave protection and to prevent the scraper from being pulled into the sheave, see Fig. 6.

The sheave saddle is a 4-bolt anchor set in the concrete at the end of the slusher drift approximately 6 ft above the floor. For ventilation purposes a 20-in. diam pipe is poured in concrete 11 ft from the end, so that it can be connected with the ventilation drift below. It is large enough to allow a man to travel through it in an emergency.

Fig. 7—View of concreted slusher drift shows recess left for drawpoint.

Fig. 8—Slusher drift, concreted as described, has required little maintenance.

The slusher drift is designed to stand a static head of at least 586 psi (500 ft of height) and to produce approximately 200,000 tons of comparatively soft rock. Although it does not often do so without some maintenance, it stands up well, and in some cases drifts have handled much more tonnage without any repair. Most failures come from point pressures which cause crushing. There is excessive wear on the floor at the delivery end and on the drawpoint brows, but this is easily repaired. At present, experiments are being carried out to ascertain to what extent heavy rails are necessary in the floor or, if they are desirable at all except for the first 20 ft at the delivery end. Steel rails were used at one time, but it was found that they were very little help in saving the walls. Fig. 8 is a view of the completed slusher drift in production.

There is no doubt that changes for the better will be made in this drift. At present, however, it is a very productive, low-maintenance slusher drift.

As concrete is used in such large amounts and so efficiently, it should be mentioned separately. Mixing is done on surface at a central automatic batching plant. Transportation is by shooting with a Press-Weld placer through a 6-in. pipe with compressed air for distances up to 2500 ft. Of this, 2000 ft is horizontal and about 500 ft is down a vertical shaft. Advantages of this method over the pumpcrete are many. Concrete can be placed at a much lower cost per yd, and a regular, more consistent mix is made. Congestion in the haulage crosscuts is also avoided because the concrete is carried in a 6-in. pipe either on the floor or back. Up to 80 yards have been poured in one shift.

## Part II

# Undercutting Technique

by D. L. Monroe

UNDERCUT development follows an advancing panel of slusher drift units 100x50 ft in area. This is further broken down into areas 35x25 ft over individual drawpoints, each of which is prepared for undercutting as a self-contained blast, and drawpoints for each slusher drift are grouped for simultaneous undercut blasting, Figs. 1 and 2.

The undercutting method now in use has served for the last six blocks with a minimum of modification. It is flexible enough to cope with all ground conditions encountered, except that extremely soft rock or extremely hard rock, and especially mixtures of the two, require special attention.

Undercutting consists of opening the bells over each drawpoint to the top of the undercut, wide enough to join each to its neighbor. This is done by opening a narrow vertical slot at right angles to the slusher drift and slashing parallel fans of holes to it to develop the combined drawpoint and undercut excavation. The success of the undercut depends on the slot. It extends to the margin of the undercut area and serves to outline the excavation as well as to provide the free faces and expansion for the final undercut blast, see Fig. 3.

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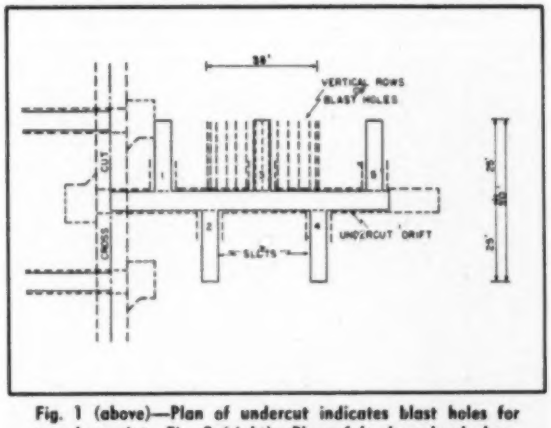
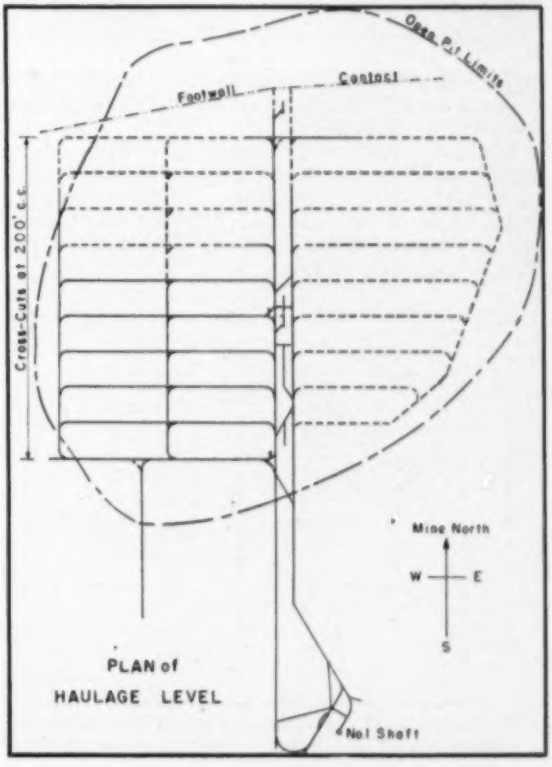



Fig. 1 (above)—Plan of undercut indicates blast holes for one drawpoint. Fig. 2 (right)—Plan of haulage level shows crosscuts that divide orebody into sections. Caving unit is 200 ft square.

### Development

An undercut drift is driven directly above and parallel to each slusher drift. It is kept to a minimum cross-section and is opened no sooner than necessary to allow a continuous sequence of under-



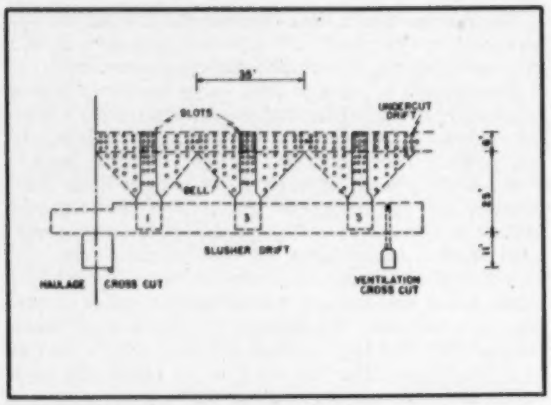



Fig. 3—Section shows placement of holes for drawpoint excavation. Drilling is with jacklegs.

cut preparation. It is often supported by steel sets and occasionally gunited as required. The undercut is drilled from this drift in a continuous pattern designed to progress from the bottom to the top of the slot and then out to the sides of the excavation. All drilling is completed before any blasting is started and, once started, blasting pauses only long enough to assure the complete breaking of the slot before proceeding with the rest of the holes.

The slot is opened by a footwall raise, a slot raise and the slot holes. The footwall raise is driven from the drawpoint to the undercut level at right angles to the slusher drift and establishes the footwall of the slot and of the future bell. This raise may be replaced by a pattern of footwall holes which, when blasted with the slot, are enough to clean up the footwall. This is all the work which is done from below, the rest being confined to the undercut drift above, as shown in Figs. 4 and 5.

The slot raise is drilled downward from the undercut drift to break through on the centerline of the drawpoint below. The slot raise and the footwall raise then form a vertical *V* at right angles to the undercut drift from the undercut down to the mouth of the drawpoint.

The slot is opened by blasting holes drilled from the undercut drift to break to the slot raise, forming a triangular slot extending from the drawpoint to the back of the undercut. Where footwall holes are used instead of the raise they are blasted at this time to clean the footwall.

The balance of the undercut drilling follows the pattern established by the slot drilling and consists of fans of holes at right angles to the undercut drift. Each fan contains holes drilled horizontally to the limit of the undercut area and downward to conform to each vertical section of the drawpoint bell. These rows are designed to be slashed to the slot, retreating from deepest near center to shallowest at the ridge between drawpoints, Fig. 5.

Each drawpoint is prepared as an independent unit to be blasted as part of a group to form a complete undercut across the area to be caved. Every drawpoint and every undercut prepared to date has continued to cave successfully.

Undercut drilling is now done with jacklegs using ⅞-in. hexagonal sectional steel and 1⅜-in. tungsten carbide chisel bits. Holes are drilled up to 25 ft in length at averages of 125 ft per man shift with as much as 200 ft per shift having been reported. For the slot raise a *leyner,* sectional steel, and 3¼-in. and 2-in. steel bits are used, Figs. 6-11.

A 25-ft length of plastic hose is used for blowing holes, Fig. 7, and sectional plastic sticks are used for loading, Fig. 10. Polar Forcite Gelatin 40 pct and millisecond delay electric blasting caps are used.

A separate crew is maintained for undercutting and includes a blast hole foreman, an assistant foreman, who doubles as blast hole engineer, three shift foremen and about 30 miners. This crew operates as a unit and handles all phases.

Work follows prepared plans for drilling, loading, and blasting. The drilling plan serves as an indication of required departures from standard drilling patterns and as a check chart for holes drilled. The loading plan is a record of holes actually drilled, amended as required when the holes are blown, and on it are shown the powder and caps to be used. The blasting map is a completed loading plan on which all last-minute changes have been noted. The blasting circuits are worked out on this map ahead of time and are followed in the undercut drift when connecting up the blast. Records are kept of all phases of the undercutting operation up to and including actual date and time of final blast.

## Advantages

Several advantages are claimed for this method. Safety to personnel is improved in that a minimum of drilling is done in and beneath the drawpoints and all other work is concentrated in the undercut drift. Control of drilling, loading, connecting, and

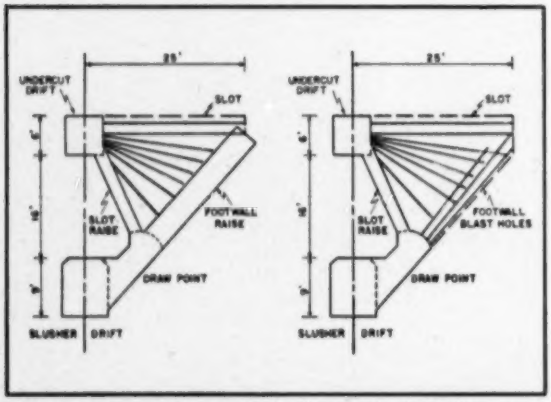



Fig. 4—Cross-section of slot development by footwall raise, left, and by blast holes, right.

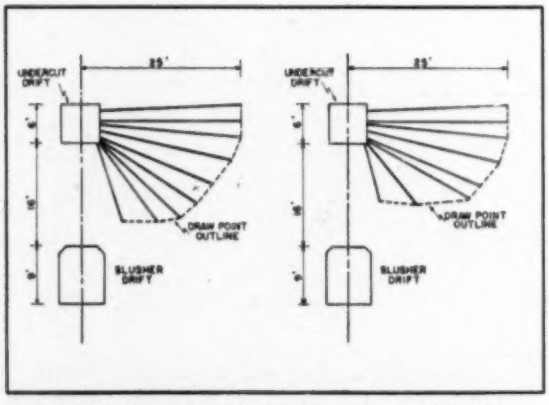
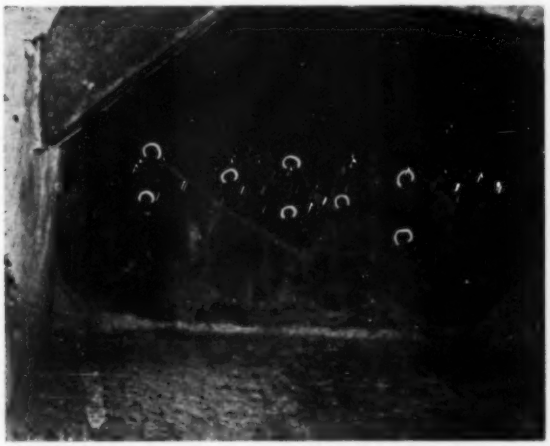



Fig. 5—Cross-section of first and second rows of the holes that slash to the already opened slot.

Fig. 6—Jackleg set up for drilling first row of holes from the undercut drift.

Fig. 7—This 25-ft length of plastic hose is used for blowing holes.

Fig. 8 (above, left)—Sectional steel is used for drilling up to 25 ft. Fig. 9 (above, center)—Leyner and sectional steel are used for the slot raise drilling. Fig. 10 (above, right)—Sectional plastic sticks speed loading. Fig. 11 (below)—View into mouth of concreted drawpoint shows footwall holes to be blasted with the undercut. Other holes are drilled from undercut drift above for maximum safety. Fig. 12 (right)—This undercut drift in bad ground is being supported with steel sets; gunite is also used occasionally. Drift is kept to minimum section and opened no sooner than necessary.



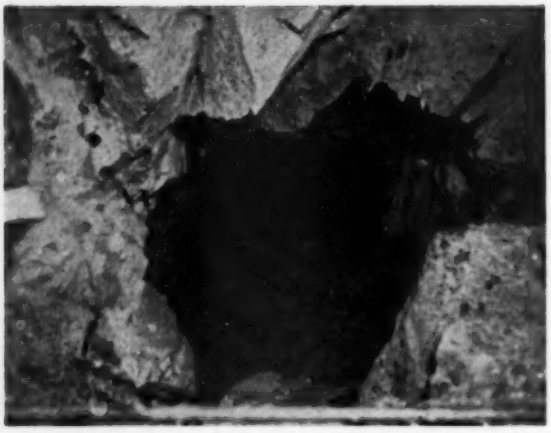


Fig. 14 (above)—Drawpoints in poor ground such as this receive individual attention.

Fig. 13 (left)—A view of completed slot in good ground.

blasting is facilitated in that work is laid out on plans and the whole undercut unit is prepared in one heading. Completion of an undercut, once started, is more certain in that a local ground failure, which is difficult to avoid entirely, need only affect the drawpoint in which it occurs. The hazard of ground failure is greatest at the junction of the slot and undercut drift. The slot is kept to a minimum width and is delayed for blasting as late as possible. Often the collars are left on the slot holes to bolster the undercut drift until the final blast. Instances occasionally arise where the slot cannot be maintained until blasting time and many holes are lost. Ground conditions then are usually so poor that the balance of the drawpoint will cave or be cleaned up by what holes may be salvaged. Drawpoints in such bad ground are identified beforehand and given individual attention, Figs. 12 to 14.

The undercutting method in use is well suited to average ground conditions and is flexible enough to allow occurrences of poor ground to be handled without altering plans for the whole undercut. It gives the greatest assurance possible under such varying rock strengths of a complete undercut across the area to be caved, and this is regarded as a prerequisite to successful operation.

## Part III

# Aluminum Forms for Concreting Mine Headings

by D. P. R. Smyth

ALL mine haulage and development openings at the Jeffrey mine are big enough for large-scale equipment. The ground is very weak. Permanent openings require concrete for support and aluminum forms are used for concreting slusher drifts, haulage drifts, and shafts. These forms improve the efficiency of concrete placement in all headings where they are used.

Roughly 65 pct of all mine concrete is poured in slusher drifts and draw points. Slusher drifts are located 11 ft above haulage drift rail base. Forms for slusher drift concreting must be moved by hand. It was early recognized that some kind of portable reusable forms should be used and that they should be made of the lightest possible material if labor costs were not to be excessive. Plywood forms were tried but after their second use some splintering of the forms was observed. Since in asbestos mining it is imperative that wood and other scrap be kept out of the ore, this splintering proved them unsatisfactory and attention turned to aluminum.

Aluminum Company of Canada Ltd. was consulted as to the suitability and availability of various aluminum alloys. It was decided that Alcan 65ST aluminum alloy would be used. This alloy belongs to the Al-Mg-Si series of alloys which are characterized by medium strength, good forming qualities, and good corrosion resistance. It welds satisfactorily, but that was not a deciding factor because the form design called for rivets and bolts only. Since then other designs have employed welding with very satisfactory results.

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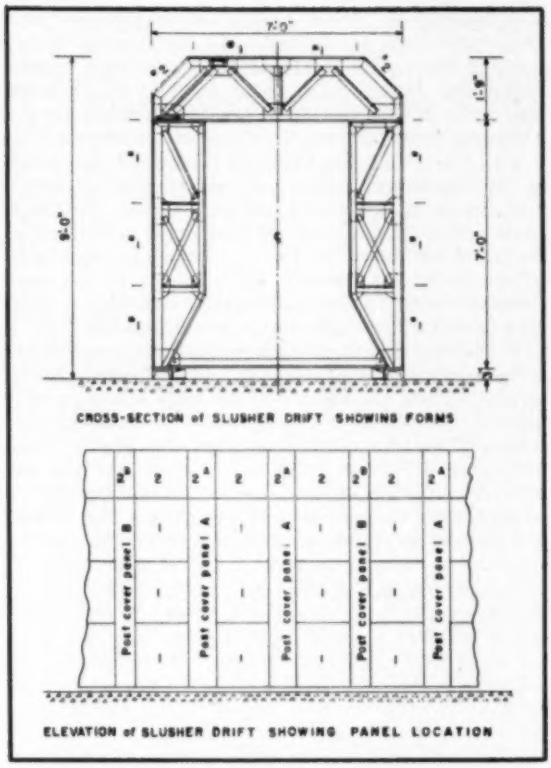
CROSS-SECTION of SLUSHER DRIFT SHOWING FORMS
Post cover panel B
Post cover panel A
ELEVATION of SLUSHER DRIFT SHOWING PANEL LOCATION

Fig. 1—Supporting truss for aluminum forms.

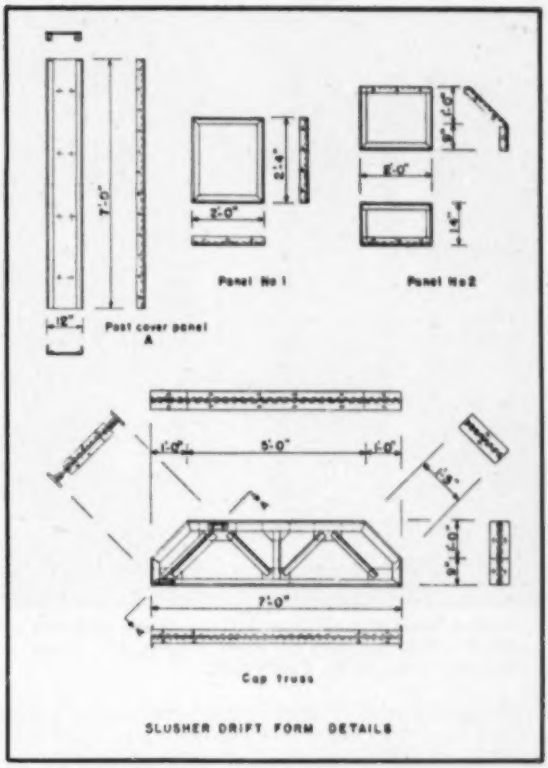


Fig. 2—Separate parts of slusher drift form.

## Slusher Drift Forms

The cross-section of the slusher drift in Fig. 1 shows the supporting truss for the aluminum forms. Main members are made up of 3x3x⅜-in. angles riveted back-to-back to the gusset plates, while supporting members are 2x2x¼-in. angles similarly joined. The post truss is set on an inverted 6-in. channel and is wedged up slightly from the channel so that it can be more easily removed when the forms are being stripped. The elevation in Fig. 1 is a diagrammatic sketch showing where the panels are located in the slusher drift. Post cover panels are made in both 9 and 12-in. widths. No. 2B and No. 2A panels conform with the post cover panels.

The *cap truss*, detail, is in Fig. 2; see also Figs. 3, 4. When cap cover panels are bolted into place the nut should be in the concrete. Sometimes workmen forget this and put the nut on the inside of the forms. Stripping then becomes more difficult and forms may become twisted or bent. To obviate this abuse the cap truss is split as shown at section A-A on the drawing and can be dismantled in two parts.

The details of post cover panel A and of panels No. 1 and No. 2 are also shown; ¼-in. plate with 2x2x¼-in. angles is used throughout. The panels not shown are similar in construction. Except for post and cap cover panels, all bolting is done inside the forms.

Weights of the various panels are as follows:

| | |
|---|---|
| Panel No. 1 and panel No. 2 | 25 lb ea. |
| Upright post truss without cover panel | 75 lb |
| Cap truss | 71 lb |

Fig. 3 (above)—Close-up shows cap truss in place.

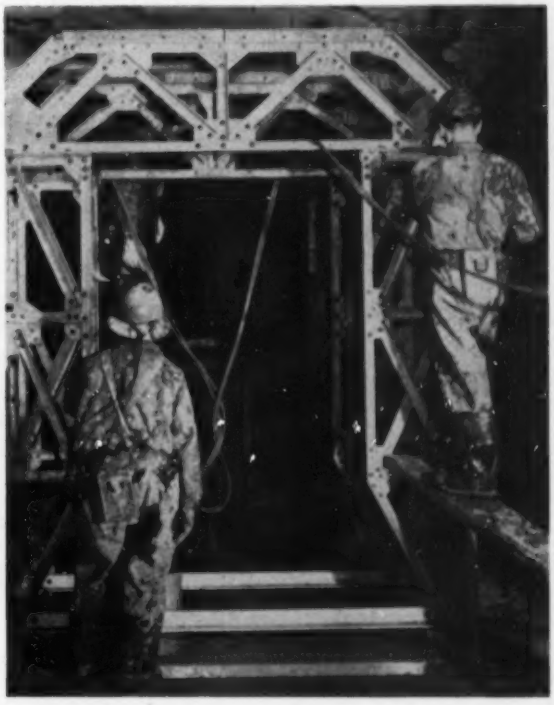

Fig. 4 (right)—Erection of slusher drift forms.

Fig. 5—These 4x6-ft aluminum shaft form panels weigh only 202 lb. They replaced steel panels weighing 611 lb and were used in sinking No. 2 main shaft.

Aluminum slusher drift forms have been in service for over 3½ years. As yet none has worn out. They are handled roughly and they have stood up to it. Some go to the shop to be straightened but there is very little breakage of member parts. A close examination of the oldest forms fails to find any pitting or corrosion. Steel forms used for concreting must be painted with lubricating oil before the concrete is poured or the forms will stick to the concrete very tenaciously. Aluminum forms are not painted and can be pulled off the concrete easily.

Experience with aluminum forms in slusher drifts led to their use in other headings. The No. 1 main shaft was sunk using steel forms for concreting. A steel panel 3 ft-10 in. x 6 ft-0 in. employing ¼-in. plate, 3x3x½-in angle, and 4x4x½-in. angle weighed 611 lb. Wider panels weighed proportionately more. All panels had to be handled by tugger hoist or other mechanical means. Aluminum panels, measuring 4x6 ft, now being used in No. 2 main shaft, weigh 202 lb. They are handled mainly by mechanical means but are much easier to place.

Fig. 5 is a close-up view on surface of one panel of the aluminum forms used in No. 2 main shaft. The 4x4-in. H-beams are riveted to ¼-in. aluminum plate and 2x2x¼-in. angles horizontal are added to facilitate handling the forms. Angles on each side of the forms vary to suit shaft timber or the next panel of forms. Alcan 65ST aluminum alloy is used throughout except that rivets are Alcan 55ST33.

In earlier mine development main haulage drifts were excavated in rectangular shape and timbered with steel sets placed at 6-ft intervals and then concreted into place. Forming for the concrete was done on the spot with steel plate and 4x4-in. steel H-beams. To obviate the use of steel sets and yet provide sufficient ground support a dolly-mounted arched-back steel form was designed. The bottom of the form is braced to the track and traffic can be resumed as soon as the form is placed, Figs. 6, 7.

Each 4-ft length of steel drift form weighs 1984 lb. A similar aluminum form weighs 612 lb. The final phase of levelling and lining up the forms is done by hand and the lesser weight of the aluminum makes it easier and safer to handle. The aluminum form also lends itself to use on reconstruction jobs where the dolly cannot go. The bottom section of the form is removed, the main section is divided in two by unbolting the top hinge and the largest resulting segment weighs about 215 lb which can be carried manually for short distances. The identical section of the steel form weighs about 700 lb and cannot be carried.

In an ordinary drift location, a crew working with the aluminum arched forms accomplishes from 40 to 50 pct more work than a crew does when erecting arched steel forms. Because aluminum forms for concreting have proved so adaptable and so economical of labor, the Jeffrey mine staff is planning to use them on all jobs where concreting can be standardized.

Fig. 6—Arched haulage drift form ready for concrete.

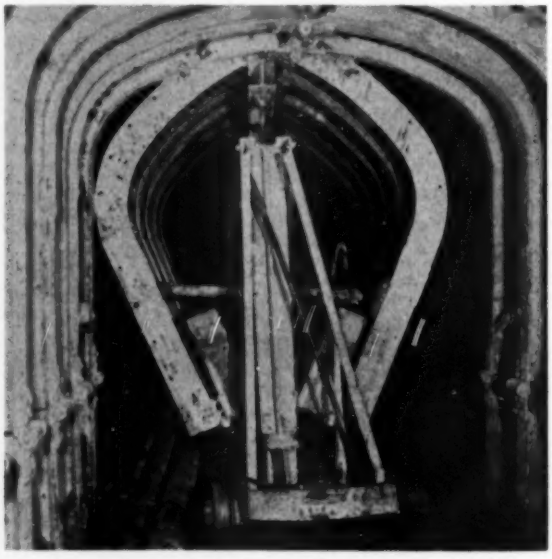

Fig. 7—Arched form being raised into place from dolly.

# Flotation and the Gibbs Adsorption Equation

by P. L. de Bruyn, J. Th. G. Overbeek, and R. Schuhmann, Jr.

THE technique of concentrating valuable minerals from lean ores by flotation depends upon the creation of a finite contact angle at the three-phase contact, mineral-water-air. If the mineral is completely wetted by the water phase, contact angle zero, there is no tendency for air bubbles to attach themselves to the mineral. However, when the contact angle is finite, the surface free energy of the system, water-air bubble-mineral particle, can be diminished by contact between the bubble and the particle, and if not too heavy the mineral will be levitated in the froth.

With a few exceptions, all clean minerals are completely wetted by pure water. Thus the art of flotation consists in adding substances to the water to make a finite contact angle with the mineral to be floated, but to leave the other minerals with a zero contact angle. The contact angle concept and experimental measurements of contact angles have played important roles in flotation research for several decades.[1-3] Nevertheless, there remain unanswered some basic questions as to the scientific significance of the contact angle and the nature of the processes by which flotation reagents affect contact angles.

The contact angle is a complex quantity because the properties of three different phases, or rather of three different interfaces, control its magnitude. Considering the interfaces close to the region of ternary contact to be plane, the relation among the contact angle and the three binary interfacial tensions is easily derived. The condition for equilibrium among the three surface tensions, Fig. 1, or the requirement of minimum total surface free energy leads to Young's equation, Eq. 1:

$$\gamma_{SA} - \gamma_{SL} = \gamma_{LA} \cos \theta \qquad [1]$$

According to this equation, the contact angle has one well-defined value. Actually it is found in many experiments that the value of the contact angle depends on whether the air is replacing liquid over the solid (receding angle) or the liquid is replacing air (advancing angle). The receding angle is always the smaller of the two.[4]

Two explanations have been offered for this experimental fact. According to some investigators,[5-8] roughness of the surface causes apparent contact angles that are different for the receding and the advancing cases although the actual local contact angle may be completely determined by Eq. 1. The other explanation involves the hypothesis that the solid-air interface after the liquid has just receded is different from the same interface when no liquid has previously covered it.[1, 4] Adsorption of constituents of the air or liquid might play a role here.

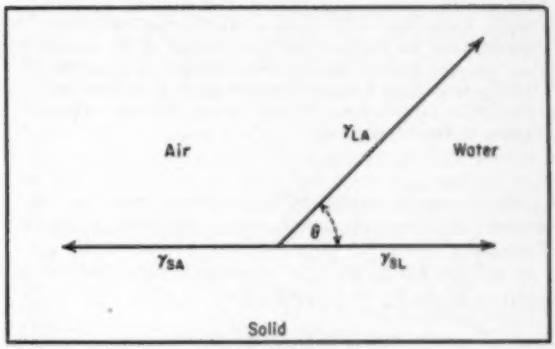


Fig. 1—The three-phase contact.

In this discussion the difference between advancing and receding contact angle will be neglected and plane surfaces where Eq. 1 describes the situation will be considered. But there is still a fundamental obstacle to the application of Young's equation. The surface tension of the liquid ($\gamma_{LA}$) can easily be determined, but the two surface tensions of the solid ($\gamma_{SA}$ and $\gamma_{SL}$) cannot be measured directly. Eq. 1, however, is not without value. By contact angle measurements it is possible to establish how $\gamma_{SA} - \gamma_{SL}$ varies with the addition of solutes to the liquid phase. Also, Eq. 1 affords a convenient starting point for calculating net forces and energy changes involved in the process of bubble-particle attachment.[1, 9] If for the moment surface tension of the liquid ($\gamma_{LA}$) is considered a constant, an increase in $\gamma_{SA} - \gamma_{SL}$ will tend to decrease the contact angle. A decrease in $\gamma_{SA} - \gamma_{SL}$ corresponds to an increase of the contact angle. In cases where $\gamma_{SA} - \gamma_{SL} > \gamma_{LA}$ the contact angle is zero; it will only reach finite values when $\gamma_{SA} - \gamma_{SL}$ has been decreased below $\gamma_{LA}$. Thus on the basis of Young's equation and contact angle measurements alone, it can be learned how flotation reagents affect the difference $\gamma_{SA} - \gamma_{SL}$, but no conclusions can be drawn as to the effects of reagents on the individual surface tensions $\gamma_{SA}$ and $\gamma_{SL}$, not even as to signs or directions of the surface tension changes resulting from reagent additions.

A quantitative relationship between the surface tension or interfacial tension and the adsorption occurring at a surface or an interface is given by the Gibbs equation, which for constant temperature and pressure reads

$$d\gamma = -\sum_i \Gamma_i \, d\mu_i \qquad [2]$$

where $d\gamma$ is the infinitesimal change in surface tension accompanying a change in chemical potential

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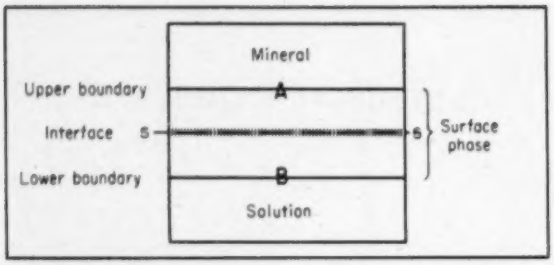


**Fig. 2—The surface phase between mineral and solution. Planes A and B are on each side of the interface, sufficiently distant from the interface that the portions of the system not included between them can be regarded as completely homogeneous bulk phases. The mathematical dividing surface SS is usually chosen in such a way that the surface excess of the solvent is nil.**

$d\mu_i$ of the component i of the system and $\Gamma_i$ is the number of moles of component i adsorbed per cm² of surface.

In dilute solutions, the chemical potential of a solute is given by the expression

$$\mu_i = \text{const.} + RT \ln c_i \qquad [3]$$

where $R$ is the gas constant, $T$ the absolute temperature and $c_i$ the concentration of component i in the bulk solution. The "const." depends on the solvent and on the units of concentration but not on the other solutes that are present in small amounts.

For the derivation of Eq. 2 the reader is referred to the literature.[6, 10, 11] If this equation is to be used intelligently, it is necessary to be explicit about the meaning of $\Gamma$ and also to define correctly the components of the system to which the summation applies. Moreover, it should be emphasized that the Gibbs equation is applicable only when the surface is in equilibrium with the bulk phases.

Gibbs[10] pointed out in his fundamental treatise that the adsorption of any one substance cannot be defined in an absolute way. The adsorption of one chemical species can be expressed only in terms of that of another species. The amount adsorbed ($\Gamma_i$) may be defined as the excess amount of substance i present in the surface phase, that is, in the interface (or surface), plus the adjacent regions of the bulk phases, see Fig. 2. This excess is equal to the amount of substance i in the surface phase minus the amount of i which would have been present if the volume occupied by the surface phase were filled instead with the two homogeneous bulk phases separated by a mathematical surface. Defined in this way, $\Gamma_i$ varies with the choice of position for the mathematical surface, since this choice determines the relative amounts of the two bulk phases which would theoretically have to be used to fill the volume of the surface phase. This uncertainty in the definition of $\Gamma_i$ does *not* affect the value for the change in surface tension ($d\gamma$) in Eq. 2, because in the bulk phases the Gibbs-Duhem relation[10, 12]

$$\sum_i \Gamma_i \, d\mu_i = 0 \qquad [4]$$

is valid, where $n_i$ is the number of moles of component i per unit volume. It is therefore immaterial where the mathematical dividing plane is placed or how much of the bulk phases is considered to belong to the surface phase. Often this plane is conveniently chosen so that one component, usually the solvent, is not adsorbed at all but belongs completely to the solution phase, see Fig. 2. This convention actually corresponds to the analytical definition of adsorption ordinarily used in experimental studies of adsorption from dilute solutions. Therefore, the summation in Eq. 2 must be extended to all components of the system including the mineral itself or to all components except the solvent if the assumption is made that the solvent is not adsorbed.

A further important point to consider is whether ions or neutral substances should be chosen as the components of the system. In principle this choice does not affect the final result, but since different ions as a rule are not adsorbed in equivalent amounts, it is often preferable to consider ions as the components. However, electroneutrality must be preserved both in the bulk of the solution and at the interface, and therefore the number of independent components is one less than the total number of ionic species present. Usually one or more relations exist among the chemical potentials of ions which further restrict the number of variables; for example, $\mu_{M^+} + \mu_{A^-}$ is a constant and the solubility product of the mineral is a constant.

The relations can be handled very simply as follows: First write the Gibbs equation, Eq. 2, and consider the summation to be carried out for all ionic and neutral components except the solvent. Then introduce the principle of electroneutrality in the $\Gamma$'s, use the relations among the chemical potentials to reduce the number of variables, and finally combine the chemical potentials of ions into those of salts, thus taking the electroneutrality of the solution into account.

*Application to Flotation:* Flotation systems usually contain such a large number of components that writing down the complete Gibbs equation for them, though not impossible or even difficult, would be tedious. Fortunately, in most cases what happens during simultaneous changes of all the chemical potentials is not of interest, but rather the effects produced by the addition of a single substance (collector, activator or depressant) to the system.

The Gibbs-Duhem relation, Eq. 4, shows that the chemical potential of *one* component cannot be altered without changing at least one of the others. In a dilute solution, however, the addition of a small amount of substance A to the system can be considered to change only the chemical potential of this component and that of the solvent. The chemical potentials of all the other components remain unchanged. Furthermore, the mineral is present as a separate phase and has, therefore, a constant chemical potential. When chemical reactions between the added substance and one or more of the other components occur, more complete forms of the Gibbs equation have to be considered.

The application of the Gibbs equation to a flotation system presupposes that equilibrium is attained or at least closely approached. Thus if the Gibbs equation is found consistent with experimental facts on actual systems, such agreement may constitute indirect evidence of attainment of equilibrium.

*Influence of the Collector. A Simple Collection System:* First to be considered is the addition of a collector that does not give rise to any chemical reactions or precipitations of insoluble phases. The solution already may contain any number of solutes which may or may not be adsorbed at the surface, but the concentrations and chemical potentials of these solutes will be kept constant.

If the collector is a neutral molecule, $X$, the Gibbs equation for addition of the collector would be

$$d\gamma = -\Gamma_X\, d\mu_X - \Gamma_{H_2O}\, d\mu_{H_2O} \qquad [5]$$

On the other hand, if the collector is an electrolyte, say $C^+X^-$, where $X^-$ is the active collector ion and $C^+$ an inorganic cation like $Na^+$, $H^+$ or $NH_4^+$, the Gibbs equation will contain three terms,

$$d\gamma = -\Gamma_{X^-}\, d\mu_{X^-} - \Gamma_{C^+}\, d\mu_{C^+} - \Gamma_{H_2O}\, d\mu_{H_2O} \qquad [6]$$

In Eqs. 5 and 6, the last term, $\Gamma_{H_2O}\, d\mu_{H_2O}$, is zero, if the convention is used that the adsorption of the solvent ($\Gamma_{H_2O}$) is zero. Usually, the second term in Eq. 6 can be neglected either because the adsorption of the cation ($\Gamma_{C^+}$) is small or because the concentration of the cation is already determined by the presence of an inorganic salt so that $d\mu_{C^+}$ is negligibly small.

It might be argued that if the collector ion is adsorbed by an ion exchange mechanism as demonstrated for chalcocite by Gaudin and Schuhmann[14] and for galena by Taylor and Knoll,[15] a term or terms for the exchanged anions ($SO_4^=$, $OH^-$, $CO_3^=$) should be added to Eq. 6. These terms, however, will be small, especially if the volume of the solution is large compared to the amount of mineral. The number of anions released to the solution by this ion exchange will hardly change the concentration of these anions in the solution; therefore, the relevant $d\mu$'s are very small and may be neglected.

In all cases of flotation, the collector is positively adsorbed to the mineral. This means that $\Gamma_X$ or $\Gamma_{X^-}$ is a positive quantity if $\Gamma_{H_2O}$ is considered to be zero. Consequently, according to Eqs. 5 and 6, the addition of a collector *lowers the interfacial tension $\gamma_{SL}$ between mineral and solution.*

According to Eq. 1 and Fig. 1 this decrease of $\gamma_{SL}$ would lower the contact angle. Experiments, however, show an increase in the contact angle under these conditions. The experimental observation cannot be explained by an increase in the surface tension $\gamma_{LA}$, which, if affected, decreases slightly on addition of the collector. Neither can failure to reach equilibrium at the mineral-solution interface account for the increase in contact angle because this would only make the change in interfacial tension smaller and would not reverse its sign.

The conclusion is apparent, therefore, that in the collector system considered here the increase in contact angle has to be explained by a *decrease of the surface tension mineral-air* ($\gamma_{SA}$), a decrease which has to be larger than the decrease in $\gamma_{SL}$.

The decrease in the surface tension mineral-air is evidently brought about by adsorption of the collector to that surface. If the mineral-air interface is in equilibrium with the solution, the chemical potential of the collector should be the same at the mineral-air and the mineral-solution interface. A larger change in $\gamma_{SA}$ than in $\gamma_{SL}$ then demands a higher adsorption of the collector at the solid-air interface.

This analysis indicates that a collector should show not only a special affinity for the mineral, but in addition a tendency to prefer the mineral-air to the mineral-water interface. It should have, therefore, a strong hydrophobic group. As bases of an opinion on the qualities and possibilities of collectors, adsorption studies at the mineral-solution interface are certainly valuable and important, but for a good understanding of flotation more information on adsorption at the mineral-air interface seems indispensable.

*Precipitate Formed by Collector. A More Complex System:* Analogous conclusions are reached in the somewhat more complicated system where the collector ion forms a precipitate with one of the ions furnished by the mineral. Especially in xanthate flotation of sulphide minerals does this situation sometimes occur.[14] Taggart and Hassialis[16] have suggested that the solubility product of the compound between the collector ion and an ion from the mineral must be reached if collection is to occur. Without committing themselves to this point of view, the authors wish to show how the Gibbs equation must be treated in the case of precipitation.

Assume a system consisting of a mineral $M^+A^-$, a collector $Na^+X^-$, a salt $Na^+B^-$ and water. The compound $M^+X^-$ is assumed to be only slightly soluble and the amount of salt is large enough that addition of $NaX$ does not change the chemical potential of the sodium ion. For the process of adding collector to this system the essential form of the Gibbs equation is

$$d\gamma = -\Gamma_{M^+}\, d\mu_{M^+} - \Gamma_{A^-}\, d\mu_{A^-} - \Gamma_{X^-}\, d\mu_{X^-} - \Gamma_{H_2O}\, d\mu_{H_2O} \qquad [7]$$

When both $M^+A^-$ and $M^+X^-$ are present as solid phases, the constancy of the solubility products can be expressed:

$$d\mu_{A^-} = -d\mu_{M^+} = d\mu_{X^-} \qquad [8]$$

With the assumption of zero adsorption of $H_2O$, Eq. 7 then becomes

$$d\gamma = +(\Gamma_{M^+} - \Gamma_{A^-} - \Gamma_{X^-})\, d\mu_{X^-} \qquad [9]$$

and with the condition of neutrality of the surface

$$d\gamma = (\Gamma_{B^-} - \Gamma_{Na^+})\, d\mu_{X^-} \qquad [10]$$

The value and even the sign of $d\gamma$ thus depend critically upon the detailed composition of the surface. If the adsorption of $X^-$ is essentially an exchange with $B^-$ and the adsorption of $Na^+$ is negligible, $\Gamma_{B^-}$ will be positive as long as the exchange is not complete and Eq. 10 indicates that the interfacial tension *increases* with addition of collector. On the other hand, if the adsorbate is essentially $Na^+X^-$ and the adsorption of $B^-$ is small, Eq. 10 indicates that the surface tension *decreases* on collector addition.

In either case, however, the change in surface tension at the mineral-air interface is very important. If $\gamma_{SL}$ goes down, $\gamma_{SA}$ should go down more in order that a contact angle may develop. But, if $\gamma_{SL}$ increases, $\gamma_{SA}$ should increase more slowly. Assuming equilibrium to exist, this again means that $\Gamma_{B^-}$ on the mineral-air interface should be smaller than $\Gamma_{B^-}$ on the mineral-solution interface. In either case, an increase in contact angle results from collector addition only if the collector adsorption is greater at the mineral-air interface, just as in the simple collection system discussed earlier.

This example illustrates how important the determination of the adsorption may be, not only of the collector, but also of other components of the system.

*Relation to Other Approaches:* The usual explanation of collection is that the collector becomes adsorbed on the mineral surface with its hydrophobic end turned away from the mineral, thus leaving the surface hydrophobic or water-repellent. The same basic considerations are involved in this explanation

and in the approach based on the Gibbs equation. A collector should be easily adsorbed and should contain a hydrophobic part in its structure. The difference between the two approaches lies in the qualitative nature of the explanation based on the hydrophobicity of the surface as opposed to the quantitative character of the approach by the combined use of the Gibbs and Young equations.

*Activation:* An activator is a solute which promotes the flotation of a mineral by a collector which otherwise would have no effect on the mineral. A generally accepted explanation of activation is that the activating ion is adsorbed on the mineral and acts as a bonding agent between the mineral and the collector.

Several different forms of the Gibbs equation may be used to represent the effects of activators, and the choice will depend on what aspect of activation is being considered and on whether or not side reactions such as precipitation need to be considered.

First, if collection and activation occur without any precipitation reactions," Eqs. 5 and 6, already discussed for simple collection systems, are still applicable in the presence of an activator. However, for minerals requiring activation, $\Gamma_{Z^+}$ or $\Gamma_{X^-}$ and therefore $d\gamma$ resulting from an increase in collector concentration will be small or zero in the absence of the activator. A more informative approach to systems of this kind is obtained by writing the Gibbs equation for the process of increasing activator concentration, while keeping the concentrations and chemical potentials of the collector and of other solutes constant. To be specific, consider a system comprised of a mineral, a collector $Na^+X^-$, an activator $Z^+Cl^-$, and other solutes under conditions of no precipitation, complex-ion formation, or other side reactions.

The Gibbs equation for the process of adding activator then becomes

$$d\gamma = -\Gamma_{Z^+}\, d\mu_{Z^+} - \Gamma_{Cl^-}\, d\mu_{Cl^-} - \Gamma_{H_2O}\, d\mu_{H_2O} \qquad [11]$$

If chloride adsorption is negligible ($\Gamma_{Cl^-} = 0$) or if initial chloride concentration is large enough that the activator addition causes no appreciable change in chemical potential ($d\mu_{Cl^-} = 0$), and if the convention $\Gamma_{H_2O} = 0$ is used, the Gibbs equation for activator addition simplifies to

$$d\gamma = -\Gamma_{Z^+}\, d\mu_{Z^+} \qquad [12]$$

Thus, for this simple system in which it is postulated that no precipitation or other side reaction occurs, the addition of activator *lowers* the surface tensions of the solid. If the activator addition is effective in increasing the contact angle, clearly the adsorption of activator ($\Gamma_{Z^+}$) must be greater at the mineral-air surface than at the mineral-solution surface. Since it would not be expected that activating ions by themselves would show any special tendency to accumulate at the mineral-air surface, it must be concluded that a greater adsorption of activator at the mineral-air interface is the result of the fact that the activator and collector are jointly adsorbed, each strongly affecting the adsorption of the other.

A common characteristic of activator-collector pairs is their tendency to react metathetically to form highly insoluble precipitates, and flotation has been observed under conditions where such reaction products are present.[3] For the system in which the collector $Na^+X^-$ and the activator $Z^+Cl^-$ react to form a precipitate $ZX$, the equilibrium of the solution with the precipitate requires that

$$d\mu_{Z^+} = -\,d\mu_{X^-}. \qquad [13]$$

The Gibbs equation for addition of activator to this system then becomes

$$d\gamma = -\Gamma_{Z^+}\, d\mu_{Z^+} - \Gamma_{Cl^-}\, d\mu_{Cl^-} - \Gamma_{X^-}\, d\mu_{X^-} - \Gamma_{H_2O}\, d\mu_{H_2O} \qquad [14]$$

Omitting the terms for $Cl^-$ and $H_2O$ for reasons given earlier, and combining Eqs. 13 and 14

$$d\gamma = -\left[\,\Gamma_{Z^+} - \Gamma_{X^-}\,\right] d\mu_{Z^+}. \qquad [15]$$

If the activating ion has valence $n$ and forms with the collector a precipitate $ZX_n$, Eq. 15 would become

$$d\gamma = -\left[\,\Gamma_{Z^{n+}} - \left(\frac{1}{n}\right)\Gamma_{X^-}\,\right] d\mu_{Z^{n+}} \qquad [16]$$

Eqs. 15 and 16 show that the direction of change of the surface tension on the addition of activator depends on the number of equivalents of activator and collector adsorbed. If the number of equivalents of activator adsorbed is greater than the number of equivalents of collector adsorbed, then the addition of activator is effective in reducing surface tensions of the mineral. Conversely, if the equivalents of collector adsorbed exceed the adsorbed equivalents of activator, the surface tensions of the mineral will be increased.

According to previously held views of the nature of activation, an effective activator is bonded both to the mineral and to the collector so that the valence of the activating ion must be divided between the collector and the mineral. That is, the number of equivalents of activator adsorbed is expected to exceed the number of equivalents of collector adsorbed. For example, Gaudin and Rizo-Patrón[3] have suggested that quartz flotation with oleic acid and barium chloride involves the adsorption of equimolar quantities of $Ba^{++}$ and $O1^-$, or two equivalents of $Ba^{++}$ per equivalent of $O1^-$. For this system, the expression in brackets in Eq. 16 will be positive and the effect of adding barium is to reduce the surface tension at both the mineral-air and mineral-liquid interfaces. To account for the increase in contact angle obtained by adding $Ba^{++}$, it must then be concluded that the adsorption of $Ba^{++}$ and $O1^-$ or of the combination $BaO1^+$ must be greater at the air-mineral interface.

As more experimental data become available, it may become desirable to consider still other forms of the Gibbs equation for activation processes. For example, another possibility not considered above is an activator-collection system in which the activator and the mineral react to form a precipitate phase.

*Depression:* A depressant prevents flotation in a system where flotation would otherwise occur. The depressant therefore makes the contact angle decrease to zero.

A simple explanation of depressant action is obtained on the assumption that the depressant is adsorbed at the mineral-water interface but does not show any tendency to go to the mineral-air interface. According to this picture the depressant will lower $\gamma_{sL}$ without affecting $\gamma_{sA}$ too much. Such a behavior might be expected from hydrophilic, high molecular weight substances like starch which are used in potash and iron ore flotation operations.

Some electrolytes may act as depressants because they furnish ions which compete with the collector

ions and replace the collector at the mineral surface by ion exchange adsorption. In the absence of side reactions, the Gibbs equation for the process of adding depressants of this kind is essentially the same as for adding collector (Eq. 6 with $X^-$ a depressing ion instead of a collecting ion) and leads to the reasonable conclusion that the contact angle is reduced if the depressing ion is more strongly adsorbed at the water-mineral surface than at the air-mineral surface. This results in the extremely interesting hypothesis that *both collectors and depressants may lower the surface tensions of both the mineral-water and the mineral-air surfaces, so that the difference between collection and depression, or between flotation and non-flotation, depends primarily on whether the added reagent tends to adsorb more at the mineral-air surface or more at the mineral-water surface.* It therefore becomes of great interest that experiments be devised to compare adsorptions at the two mineral interfaces, for depressants as well as for collectors.

Depression by deactivation, e.g., cyanide depression of copper-activated sphalerite, can be considered in terms of Eq. 12, provided the depressing agent is not itself also adsorbed on the mineral. That is, the depressant reacts with the activator (complex-ion formation or precipitation) to reduce the chemical potential of the activator. To refer to Eq. 12, $d\mu_{s^-}$ will be negative and the changes in $\gamma_{sl}$, $\gamma_{sa}$, and the contact angle will be of opposite sign from those for activation when $d\mu_{s^-}$ is positive.

*Lack of Equilibrium at the Solid-Air Interface:* Even if the mineral-solution interface reaches equilibrium readily, equilibrium is not necessarily reached at the mineral-air interface. The available data do not give any indication whether equilibrium is reached or not, except in so far as the difference found between receding and advancing contact angles suggests lack of equilibrium.

Under non-equilibrium conditions the straightforward application of the Gibbs equation is no longer possible. If, however, it is possible to determine the composition of the solution with which the surface would be in equilibrium, the surface tension could be calculated by assuming that the adsorption was built up in a reversible manner. The following integral then gives the surface tension

$$\gamma_{sa} = \gamma^{\circ}_{sa} - \sum_i \int_{\mu_i = 0}^{\mu_i^{eq.}} \Gamma_i \, d\mu_i \qquad [17]$$

where $\gamma^{\circ}_{sa}$ is the surface tension of the surface in the absence of adsorbing solutes ($\mu_i = 0$) and the integral is supposed to follow only equilibrium conditions. The upper limit of integration, instead of containing the chemical potentials in the actual solution, contains the chemical potentials $\mu_i^{eq.}$ corresponding to the actual adsorption. This integration requires information on the equilibrium adsorption isotherm, that is, data showing how $\Gamma_i$ varies with $\mu_i$ under equilibrium conditions.

If adsorption equilibrium is approached both at the water-mineral and at the air-mineral surfaces under actual flotation conditions, it must be concluded that the adsorbed substances on both interfaces possess a high degree of mobility. The authors' analyses in terms of the Gibbs equation and the Young equation indicate that flotation depends on the existence of differences in adsorption densities between the part of the mineral surface in contact with air and the part in contact with water. Thus, as air spreads over a mineral surface, displacing water, the quantity of adsorbed collector should increase. The recent work of Hassialis and Myers[20] has shown a degree of mobility of adsorbed collector that may account for such an increase.

## Conclusion

The principal value of applying the Gibbs adsorption equations to flotation systems is that the results point directly to the need for experimental work in several hitherto neglected areas of the surface chemistry of flotation. Above all, the relations developed by combining the Gibbs equation with the Young equation show that more attention should be given to the mineral-air interface.

To develop further the application of the Gibbs equation to flotation systems, simultaneous measurements should be made of contact angles and adsorption isotherms on both mineral-air and mineral-solution interfaces. Since it is probable that equilibrium at the mineral-air interface will be difficult to achieve and to measure, the use of volatile collectors, e.g., mercaptans, may be advantageous. Another possible experimental approach is to use a liquid *mineral* to obtain a system in which the three surface tensions could be determined directly. The system water-mercury-gas, with addition of collectors and other flotation agents, suggests itself for these measurements.

Finally, the question of attainment of equilibrium at the mineral-air interface highlights the desirability of further studies of mobility of adsorbed species, contact angle hysteresis, and related topics.

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# Safety in the Mechanical Mining of Coal

by W. J. Schuster

**Safety in coal mines depends largely upon adequate training of the foreman. Although management must provide modern and safe equipment and at all times keep mines in first class condition from a safety viewpoint, final results will be determined by the quality of supervision.**

HANNA COAL CO., Division of Pittsburgh Consolidation Coal Co., operates three large underground mines in eastern Ohio. The section of Pittsburgh No. 8 coal seam in which these mines are located varies in thickness from 52 to 64 in. It is immediately overlain by a stratum of shaly material 12 to 15 in. thick locally known as draw slate, which is structurally very weak and which disintegrates rapidly upon exposure to atmosphere. Immediately above the draw slate as it is normally found is a band of extremely high ash material 6 to 12 in. thick known as roof coal or *rooster coal*, and above this is a stratum of conglomerate material varying from 4 to 10 ft in depth. Overlying the conglomerate is a relatively thick stratum of limestone, the first stable material above the Pittsburgh coal seam in eastern Ohio. With the method of full-seam mining that has been adopted, draw slate is shot down, loaded with the coal, and removed in the preparation plants. The roof coal then becomes the permanent roof.

The major problem in mining the No. 8 seam in eastern Ohio is control of the roof. Since the strata above the draw slate contains no material with a structure firm enough to provide self-support, the roof begins to sag in a relatively short time after the coal and draw slate have been removed. The problem thus becomes one of getting temporary safety posts under this roof as quickly as possible to prevent a break or separation from occurring either in the roof coal or in the conglomerate above it.

### Haulage System

The Pittsburgh No. 8 seam in eastern Ohio is relatively level, with only minor local dips. Throughout the Hanna Coal Co. mines, entries are generally 12 ft wide. Rooms are driven on a 60° angle on 30-ft centers and are 22 ft wide. No attempt is made to extract the 8-ft pillars between.

The entire length of main line haulage is gunited in one mine, and a major portion in another. Two of the mines have single-track main haulage roads with passways. The third, a new mine, is double-tracked, and the roof is supported by steel crossbars, 60 lb or heavier, spaced on 4-ft centers and lagged. In recent years timbering on main line and secondary haulage roads has been accomplished by one of two methods: 1—crossbars are supported on a small section of post set in a hitch hole in the rib, or 2—or a hole is drilled in the rib about 12 in. below the roof, of sufficient depth to fasten securely a short length of 40-lb rail, the bottom of the rail facing the roof, on which a short post is set directly under the crossbar. At present the hitch-hole timbering method is favored.

At two of the mines the main line haulage locomotives are 26-ton, 8-wheel units. These locomotives are of the axleless type, each wheel being individually mounted on the frame. The motorman's compartment is encircled by 3-in. armor plate for the protection of the occupants.

At the third underground mine conventional 15-ton locomotives are being used. However, these locomotives have been completely rebuilt in the company's shops. Equipment has been streamlined and quarters have been provided for two people, who are protected by heavy steel plate in much the same way described above. This modernization program has been completed on all secondary haulage locomotives at the three mines, and the company is well on the way to similar equipment of the 6-ton section locomotives. The following additional features have been included in their modernization: 1—additional support for the motors to prevent their falling to the middle of the track and derailing the locomotives should a break occur in the suspension bar support; 2—installation of additional bracing to prevent brake rigging from becoming displaced and causing derailments; 3—enclosure of all electric wiring in conduit or raceway; 4—provision of an enclosed compartment for the storage of re-rallers, jacks, and other equipment, so that they need not be carried on the outside of the motor; and 5—redesign of the end of the locomotive opposite the operator's compartment to prevent anyone's mounting from that direction. It is interesting to note that some

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manufacturers turning out new locomotive equipment have adopted similar features.

Introduction of mechanical loading emphasized the need for high-speed haulage and made it obvious that safety measures must be taken to insure the safe movement of rolling stock in the mines. At the time mechanical loading was introduced the only control over the movement of trips was the telephone. Later hand-operated block signal systems were used. Both these methods, however, were seriously limited by human fallibility, and a few years ago the main line and secondary haulage locomotives and the supply and mechanics locomotives in the three mines were equipped with carrier-type radios known as *trolley phones*. The latest safeguards are the fully automatic block signal systems, which are laid out in these mines so that lights for illumination on haulage roads are off until a locomotive enters a particular block, at which time the trolley pole which actuates the block signal also turns on the lights along that signal block. When the locomotive leaves the block, the signal of course changes and the lights go off. The trolley phone and fully automatic block systems have considerably reduced the haulage accidents experienced under the telephone and hand-operated block signal systems.

### Face Operations

All mining operations are performed with track-mounted mobile equipment. Room entry and room track use 40-lb rail on steel ties. Each room switch is equipped with a throw. In Hanna Co. mines permanent roof support is provided by steel crossbars, placed in position against the roof by mechanical timber-setting machines. These machines were designed by company engineers and built in the central machine shop under their supervision. Self-propelled, with provision for carrying a number of steel crossbars, they haul a truck containing wooden posts. The machines are equipped with mechanically operated lifting arms and an electric saw for cutting posts to the required length.

Compressed air is used for shooting. Air compressors are centrally located and air is piped to the working areas. Permissible powder is used only for such operations as shooting rolls in the bottom.

Post-mounted electric drills are used generally in company mines. Within the last few years these drills have been equipped with auxiliary foot or *dead man* switches, since there have been cases of serious injury to drillers whose clothing was caught in the rotating drill mechanism, the driller being unable to get back to the switch. The drill equipped with the dead man's switch operates only as long as foot pressure is applied on the switch, which has prevented several serious or fatal mine accidents.

Many far-seeing managements recognize that keeping their mines in first class condition from a safety standpoint also protects their investment and long-term efficiency of operation. They further recognize that if they expect their employees to get behind a safety program, they themselves, as managers and leaders, must be in moral position to earn the cooperation and safety-mindedness of the men who work in these mines. This is the crux of any successful safety program.

Coal mine accidents occur in coal mines. Prevention of accidents must therefore be carried out in coal mines. They cannot be prevented wholly in the office of a vice president, a safety director, or a superintendent. Accidents occur for one of the following reasons: 1—negligence of mine management in maintaining safety measures; 2—improper and/or inadequate supervision; 3—failure to train workers to do their work safely; 4—slackening of a worker's safety habits.

### Importance of Supervision in Coal Mine Safety Programs

When management has done all it can to eliminate accident hazards caused by dangerous physical conditions in a mine, the next important consideration is the quality of its supervision. As a general rule, workmen are only as safety-minded as their foremen. Management must first inspire its foremen to good safety leadership, and this leadership requires the same personal characteristics needed to achieve consistently good production records. Fortunately the coal industry is emerging from the days when a foreman "bossed his men" to the day when the foremen gets his results by means of intelligent advice and supervision. If workmen have a wholesome respect for the man who is their leader, there is no reasonable goal in safety or production they cannot attain. As everyone knows, a good foreman is utterly fair with each of his men, has no favorites on the crew, willingly explains the reasons for his directions, does not ask his men to do any task he would not do himself, and displays sincere interest in the personal welfare of his men and their families. Unless coal management recognizes the importance of human relationships to the success of business enterprises, there can be little hope of any advance safety-wise.

The need for good foremanship manifests itself in the next essential for a safety program: training the men in safe work habits. Over a period of years men develop certain ways of performing their particular jobs which may not be good ones. When top management gets down to the grass roots of a safety program, it becomes the foreman's task to untrain the workman in these bad habits and retrain him in new ones. It is then that he will need the respect and friendship of the workmen, for unless he modifies his criticism with genuine praise he will be deeply resented. He must make his criticisms as candidly and objectively as possible. He must correct mistakes privately rather than embarrass the men before their fellow workmen. Even constructive criticism, however, will not be effective unless he is able to convince each man that it is for his own safety and the safety of his fellow workmen that he is attempting to help him.

Many people have wondered why a workman must constantly be reminded to perform his job in a safe manner, when his doing it in an unsafe manner might cause severe injury or death to himself. The answer is that human beings are fundamentally lazy and will take the path of least resistance. The foreman's task of establishing safe work habits does not end, therefore, with his initial training of the crew. Day after day he must supplement his instructions by constantly policing his section to make sure that his men are performing their work as safely as they can. This too requires that the highest degree of good relations exist between the foreman and the men he supervises.

Here, then, is where the safety program will either stand or fall. If right thinking and proper action are not achieved at this level, they will never be achieved at any other level. And if the foreman is expected to perform this colossal job, he must be prepared to

do it. There are still foremen who believe that the kind of management described above is merely coddling the men. Skill is required on the part of top management to convince them that sound principles of human relations will work in the long run, and there have been instances when foremen's reasoning will not accommodate principles of this kind. In such cases, the extremity of separating them from management has been resorted to. The majority, however, were convinced that their management was dealing with them as they were expected to deal with their workmen, and it was reasonable for them to believe that men working for them would wish to be treated in the same manner.

The foreman is aided by the safety engineer, who accompanies him periodically on inspection of his portion of the mine, pointing out to him where he has violated company safety policy, State mine law, and Federal law or code, watching closely the work habits of the men and bringing to his attention any sub-standard performances he observes. His report is made to the mine superintendent, and copies are sent to the general safety director and the vice president. The safety engineer leaves notes of his findings with the mine foreman and the section foreman concerned.

In these inspections the safety engineer tries to avoid giving the impression that he is checking up with the intention of finding fault. For some years, on the contrary, an award system has been set up for supervisors at Hanna Coal Co., based on their safety performance, i.e., the condition of the mine for which a particular supervisor is responsible, as well as the number of lost time accidents which have occurred to men under his supervision.

For the past several years individual awards have been given to each workman who has worked for a calendar year without a lost time accident. There are some mine managers who believe that a safety award system brings the natural result of a good accident record. At Hanna Coal Co. it is believed that there is no shortcut to safety but that such awards will be of assistance to the foreman, giving him a talking point in selling safety to his men.

One of the principal philosophies of good advertising is that the product to be sold should come before the public eye as frequently as possible. The same approach applies to the selling of safety. For this reason a safety slogan contest has been sponsored for several years as a supplement to on-the-job safety work. Company employees were invited to submit slogans, one of these to be chosen as the company slogan of the year. Prizes were offered for the best slogan submitted at each mine, and a grand prize for the best of all those submitted. These contests were very successful, not primarily because of the quality of the slogans submitted, but because they created a great deal of discussion. In many instances the whole family assisted in writing the winning slogan. Once this was chosen, it appeared as if by magic all over the mines, bulletin boards, and even automobiles. It is stenciled in Scotch light on locomotives, mine cars, and cutting and loading machines. Large Scotch-light reproductions are placed at strategic points in company parking lots, wash houses, and mantrip waiting stations. Everywhere the workmen turn their eyes they see "I O U SAFETY." It is also publicized in the company house organ.

A traveling trophy has been instituted and is awarded each year to the underground mine with the lowest accident frequency rate. This award is presented to the mine management and local union officials, including the safety committee, of the winning mine at the annual picnic held for all employees and their families. The coveted honor of taking home the trophy has created a competitive spirit among the underground mines in the interests of safety. Another highlight of the annual employees' picnic is the presentation to a U. M. W. employee of a new automobile. Eligibility for participation in the drawing for this car is that the employee must have been in the company employ for the entire year, with no lost time accidents. This occasion is further exploited by the foreman, who passes out to his men each quarter a ticket indicating that he has gone one quarter of a year toward eligibility for a chance on the car.

The company is endeavoring to start training of prospective workmen and foremen before it employs them by instituting mining courses in various high schools in the area. The courses include theory and practice of mine ventilation, mine drainage, roof structure and support, and other phases of mining technology. The company safety department keeps in close touch with these classes, frequently making its members available for lectures to the students, consultation with instructors, and tours through company mines for the purpose of acquainting the various high school mining classes with mining practices they have already learned in theory. Naturally, much of the emphasis in these classes falls on the subject of safety, particularly as it relates to such matters as mine gases, mine ventilation, and roof support. The classes indirectly help to promote safety among many present company employees. Time without number workmen have commented on questions put to them by their sons concerning mining and mine safety.

No discussion of safety would be complete without mention of the importance of the Miners Safety Committee in the company's program. When committees of this kind first became active, too often management resented interference with its prerogatives by anyone representing the union. At Hanna Coal Co., however, it is believed that if mine management is sincere in promoting safety it will welcome suggestions from any source whatsoever. It is true that at times a committeeman who is radical in his views will wrongly criticize what he feels is a violation of safety on the part of management. It has been found that many of these committeemen are sincere in their criticism but ignorant of what constitutes good mining practice. Their attitude often changes materially after a training course in some of the theory of coal mining.

To summarize, it must be emphasized again that safety in coal mines, where coal is loaded by machine or by hand, depends on the conditioning and training of the foreman. The training must be thorough and continuous. It must be planned on a level that will be easily understood by the foreman and attract his attention to the extent that he will be able to advise intelligently the men whom he supervises on safe work practices. So strongly is this true that even though management provides modern and safe equipment and excellent working conditions, employees must be adequately trained and supervised if accidents are to be reduced to the lowest possible minimum.

# Evaluation of Sinter Testing

by E. H. Kinelski, H. A. Morrissey, and R. E. Powers

**A group of 17 American blast-furnace sinters, an American open-hearth sinter, an American iron ore, and a Swedish sinter were used to evaluate testing methods adapted to appraise sinter properties. Statistical calculations were performed on the data to determine correlation coefficients for several sets of sinter properties. Properties of strength and dusting were related to total porosity, slag ratio, and total slag. Reducibility was related to the degree of oxidation of the sinters.**

THIS report to the American iron and steel industry marks the completion of a 1949 survey of blast-furnace sinter practice sponsored by the Subcommittee on Agglomeration of Fines of the American Iron & Steel Institute. The use of sinter in blast furnaces, sinter properties, raw materials, and sinter plant operation have been reported recently.[1, 2]

After preliminary research and study,[3] test procedures were adapted to appraise the physical and chemical properties of sinter to determine what constitutes a good sinter. During the 1949 to 1950 plant survey each plant submitted a 400-lb *grab* sample to research personnel at Mellon Institute, Pittsburgh, Pa. A 400-lb sample was also submitted from Sweden. In addition, 2 tons of group 3 fines iron ore were obtained from a Pittsburgh steel plant. The following tests were performed on the iron ore sample and on the 19 sinter samples: chemical analysis; impact test for strength and dusting; reducibility test; surface area measurements, B.E.T. nitrogen adsorption method; S.K. porosity test; Davis tube magnetic analysis; X-ray diffraction analysis for magnetite and hematite; and microstructure.

Results of these evaluations are discussed in this paper and supply a critical look at testing procedures used to determine sinter quality.

## Sinter Tests and Results

Each 400-lb grab sample of sinter was secured at a time when it was believed to represent normal production practice at each plant. It was not possible to use the same sampling procedures throughout the survey; consequently samples were taken from blast-furnace bins, cooling tables, and railroad cars. These were very useful for evaluation of test methods, since they were obtained from plants with widely divergent operations. With the exception of Swedish sinter and sinter sample N, which were produced on the Greenawalt type of pans, all survey sinters were produced on the Dwight-Lloyd type of sintering machines.

Sinters submitted for test were prepared in identical manner by crushing in a roll crusher (set at 1 in.), mixing, and quartering. To secure specific size fractions for tests, one quarter of the sample was crushed in a jaw crusher and hammer mill to obtain a −10 mesh size. The remainder was screened to obtain specific size fractions.

The group 3 fines iron ore was dried and screened and samples were taken from selected screen sizes to be used for various tests. Prior to testing, each ore sample except the −100 mesh fraction was washed with water to remove all fine material and was then dried. This iron ore, a hematitic ore from the Lake Superior region, was used as a base line for comparing results of tests on sinters. The iron ore did not lend itself to impact testing, since it was compacted rather than crushed in the test, and no impact tests are reported. However, the iron ore was subjected to all remaining physical tests to be described.

*Chemical Analysis:* Table I presents chemical analyses performed on the survey sinter samples. Included in this table are data obtained from determination of FeO and the slag relationships: $\frac{CaO + MgO}{SiO_2}$ and total slag ($CaO + MgO + SiO_2 + Al_2O_3 + TiO_2$). The percentage of FeO was used as an indication of the percentage of magnetite in the sinter. It was believed that slag relationships could be correlated with sinter properties.

During initial determination of FeO great disagreement arose among various laboratories, both as to the results and the methods of determining values. Table I lists the values of FeO resulting from the U. S. Steel Corp. method of chemical analysis,[4] which reports the total FeO soluble in hydrochloric and hydrofluoric acids (metallic iron not removed) with dry ice used to produce the protective atmosphere during digestion. Use of dry ice was a modification required to obtain reproducible results. In this method, the iron silicates and metallic iron are believed to go into solution and are therefore reported as FeO. This is important, for in the study of the microstructure of sinters, glassy constituents suspected of containing FeO as well as crystallized phases of undetermined identity which may also contain FeO have been observed.

*Strength Test by Impact:* In evaluating sinter quality, one of the properties stressed most by blast-furnace operators is strength. This strength may be described as the resistance to breakage during handling of sinter between the sinter plant and the blast-furnace bins. It is also the strength necessary to withstand the burden in the blast-furnace. After

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## Table I. Analyses of Plant Sinter Samples

| Sinter | Chemical Analysis: Total Fe, Pct | Mn, Pct | P, Pct | $SiO_2$, Pct | $Al_2O_3$, Pct | CaO, Pct | MgO, Pct | S, Pct | C, Pct (By Combustion) | $TiO_2$, Pct | FeO Determination: Total FeO, Pct, Fe° Not Removed (HCl and HF) | Comparative Order: High, 1 Low, 10 | Slag Relationships: $\frac{CaO + MgO}{SiO_2}$ | Total Slag: CaO + MgO + $SiO_2$ + $Al_2O_3$ + $TiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 62.20 | 0.88 | 0.087 | 10.40 | | 0.60 | 0.47 | 0.023 | 0.98 | | 17.95 | 6 | 0.103 | 11.47 |
| B | 61.40 | 0.82 | 0.083 | 11.00 | | 0.60 | 0.80 | 0.027 | 0.05 | | 20.07 | 5 | 0.127 | 12.40 |
| C | 60.60 | 0.70 | 0.093 | 10.40 | | 0.50 | 0.65 | 0.035 | 0.10 | | 14.16 | 9 | 0.110 | 11.55 |
| D | 59.60 | 1.03 | 0.108 | 10.80 | | 1.60 | 0.43 | 0.033 | 0.16 | | 21.06 | 4 | 0.188 | 12.83 |
| E | 53.70 | 0.22 | 0.091 | 11.60 | | 2.30 | 5.36 | 0.027 | 0.11 | | 19.03 | 6 | 0.660 | 19.26 |
| F | 59.80 | 0.59 | 0.058 | 11.30 | 0.79 | 1.30 | 0.36 | 0.027 | 0.80 | | 22.45 | 3 | 0.147 | 13.75 |
| G | 63.20 | 0.41 | 0.101 | 7.00 | | 1.80 | 1.01 | 0.036 | 0.50 | | 20.84 | 4 | 0.400 | 9.81 |
| H | 59.40 | 0.71 | 0.102 | 12.40 | 1.36 | 1.00 | 0.51 | 0.022 | 0.11 | | 15.94 | 8 | 0.120 | 15.27 |
| I | 62.30 | 0.81 | 0.072 | 10.20 | | 0.50 | 0.51 | 0.027 | 0.14 | | 19.06 | 6 | 0.099 | 11.21 |
| J | 51.10 | 0.27 | 0.263 | 17.70 | | 3.60 | 1.30 | 0.025 | 0.05 | | 17.83 | 7 | 0.276 | 22.60 |
| $L_1$ | 69.40 | 0.12 | 0.041 | 1.70 | | 0.80 | 1.01 | 0.033 | 0.02 | | 15.95 | 8 | 1.065 | 3.51 |
| $L_2$ | 69.30 | 0.12 | 0.037 | 2.10 | | 0.50 | 0.87 | 0.030 | 0.02 | | 16.70 | 8 | 0.653 | 3.47 |
| M | 64.90 | 0.25 | 0.032 | 7.00 | 0.39 | 0.20 | 0.29 | 0.027 | 0.05 | 0.60 | 25.15 | 1 | 0.213 | 8.48 |
| N | 58.83 | 0.26 | 0.016 | 2.40 | 3.47 | 0.40 | 1.59 | 0.19 | 0.10 | 9.60 | 20.57 | 4 | 0.830 | 17.46 |
| O | 58.20 | 1.10 | 0.128 | 9.00 | | 3.80 | 2.10 | 0.027 | 0.04 | 0.80 | 16.39 | 8 | 0.655 | 15.70 |
| P | 65.60 | 0.89 | 0.147 | 8.20 | | 1.20 | 0.22 | 0.08 | 0.14 | | 15.48 | 9 | 0.173 | 9.62 |
| Q | 65.40 | 0.62 | 0.201 | 7.60 | | 1.10 | 0.43 | 0.05 | 0.10 | 0.30 | 17.88 | 7 | 0.201 | 9.43 |
| Open hearth | 66.60 | 0.40 | 0.250 | 4.40 | | 0.40 | 0.36 | 0.05 | 0.10 | | 24.42 | 1 | 0.173 | 5.16 |
| Swedish | 62.50 | 0.64 | 0.029 | 5.00 | | 3.80 | 1.45 | 0.08 | 0.09 | | 3.69 | 10 (very low) | 1.050 | 10.25 |

extensive experimentation with the tumbler test, static crush test, and impact test, the impact test (adapted from one originating with the Jones & Laughlin Ore Research Laboratory[5, 6]) was found to be more suitable in the laboratory with regard to simplicity of operation, time required, and ease of representing strength values. The test was conducted on equipment illustrated in Fig. 1. After impact the sample (originally −1.050 + 0.263 in.) was screened and the percentages of +6 mesh (U. S. sieve size) and −20 mesh were taken as the two indices of strength (determined statistically as being suitable indices). While the indices were in most cases complementary functions and one screen size would be adequate for an evaluation, both sizes are given, Table II. The +6 mesh was arbitrarily called the strength index, since it measured the amount of strong particles that withstood the impact. Likewise the −20 mesh was arbitrarily called the dusting index, since it measured the amount of weak sinter pulverized during impact.

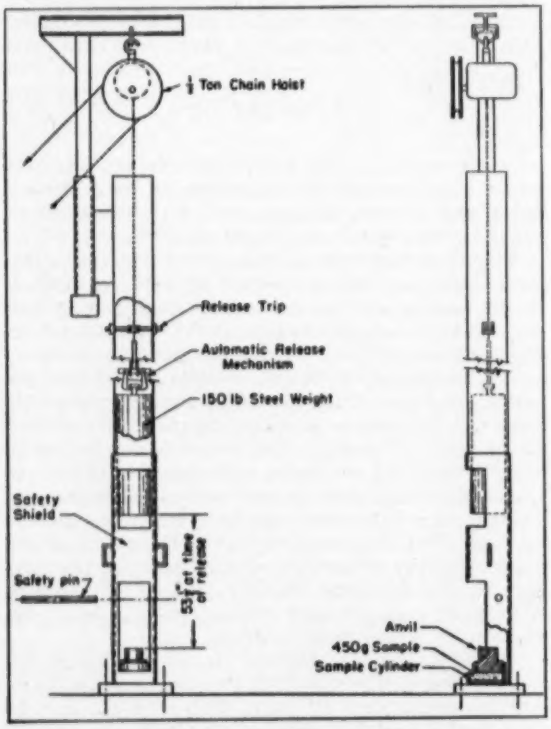


Fig. 1—Impact tester for sinter strength. After impact the sample (originally −1.050 + 0.263 in.) was screened and percentages of +6 mesh (U.S. sieve size) and −20 mesh were taken as the two indices of strength.

As evidenced by Table II, this strength index varied from 56.3 to 13.2 pct. Sinter samples A and E had the highest strength and sample $L_1$ the lowest. By comparison the sample of Swedish sinter had a value of 32.5 pct, approximately midway between the highest and lowest values. A comparative index from 1 for the highest value to 10 for the lowest value was established in an arithmetic sequence for the results in the tables.

Also in Table II, the lowest value of dusting was 15.2 pct, the highest value 34.8 pct. Furthermore, results show the least amount of dusting with samples A, B, and E, and the greatest amount with sample $L_1$ and the Swedish sample.

## Table II. Impact Strength of Plant Sinter

| Sinter | Impact Test Results: +6 Mesh, Pct | Comparative Order, Strength* | −20 Mesh, Pct | Comparative Order, Dusting* |
|---|---|---|---|---|
| A | 53.9 | 1 | 15.8 | 10 |
| B | 47.1 | 3 | 16.0 | 10 |
| C | 46.3 | 3 | 19.6 | 8 |
| D | 47.7 | 3 | 18.7 | 9 |
| E | 56.3 | 1 | 15.2 | 10 |
| F | 42.4 | 4 | 20.6 | 8 |
| G | 41.8 | 4 | 20.1 | 8 |
| H | 42.5 | 4 | 19.1 | 8 |
| I | 51.3 | 2 | 17.4 | 9 |
| J | 47.0 | 3 | 20.1 | 8 |
| $L_1$ | 13.2 | 10 | 34.8 | 1 |
| $L_2$ | 23.8 | 9 | 29.8 | 3 |
| M | 35.0 | 6 | 28.2 | 4 |
| N | 41.7 | 4 | 24.2 | 6 |
| O | 44.7 | 3 | 17.8 | 9 |
| P | 48.8 | 2 | 18.1 | 9 |
| Q | 45.3 | 3 | 20.0 | 8 |
| Open hearth | 48.2 | 2 | 20.6 | 8 |
| Swedish | 32.5 | 6 | 33.2 | 1 |
| Group 3 fines | | | | |

* High value, 1; low value, 10.

*Reducibility Test:* Perhaps the second most important property which blast-furnace operators

desire in sinter is ease of reduction. The test developed by Barrett and Wood[7, 8] was adapted and built as illustrated in Fig. 2. It was conducted at 800°C for 90 min, and loss in weight measurements were taken at intervals of 5 to 10 min. Temperature in the reaction chamber was then raised to 1000°C and reduction continued for 1 hr. A final loss in weight reading was then taken, and this value was used for calculating total oxygen available in the sinter to hydrogen reduction. Hydrogen flow rate was fixed at 0.124 cfm (STP) during the entire reduction.

In determining relative reducibility, loss in weight data was transferred into percentage reduction and plotted against time. The area under the reduction-time curve from 0 to 60 min was determined by means of a planimeter. This area was reported as a percentage of the similar area determined for group 3 fines iron ore, selected as a base line for the comparison of samples.

As Table III demonstrates, the sample of Swedish sinter had the highest relative reducibility, with a value of 98.1 pct, as compared with group 3 fines ore. The best reducibility for all samples of American sinter was 92 pct as determined for sinter sample C. The order of reducibility extended from 98.1 pct down to 51.1 pct, the latter being for sample N.

Table III. Hydrogen Reducibility of Plant Sinters

| Sinter | Reducibility | | |
|---|---|---|---|
| | Oxygen Available, Pct | Relative Reducibility, Pct | Comparative Order* of Reducibility |
| A | 23.80 | 88.4 | 3 |
| B | 24.10 | 81.5 | 4 |
| C | 24.07 | 92.0 | 2 |
| D | 22.86 | 82.5 | 4 |
| E | 20.67 | 79.0 | 5 |
| F | 23.38 | 79.8 | 5 |
| G | 24.02 | 67.4 | 7 |
| H | 23.55 | 84.2 | 4 |
| I | 23.18 | 76.4 | 5 |
| J | 19.03 | 88.9 | 3 |
| $L_1$ | 26.07 | 87.7 | 3 |
| $L_2$ | 26.33 | 84.8 | 4 |
| M | 23.37 | 71.5 | 6 |
| N | 22.32 | 51.1 | 10 |
| O | 22.44 | 81.4 | 4 |
| P | 24.30 | 88.8 | 3 |
| Q | 24.00 | 91.0 | 2 |
| Open hearth | 25.90 | 83.9 | 4 |
| Swedish | 25.10 | 98.1 | 1 |
| Group 3 fines | 28.90 | 100.0 | 1 |

* High value, 1; low value, 10.

*Surface Area Measurements:* In assessing the properties of blast-furnace sinters, mention is often made of surface area available for gaseous reduction. B.E.T. nitrogen adsorption measurements[9] for determination of surface area have been conducted, on −0.093 + 0.065 in. sieve size fractions, and results appear in Table IV. Of special interest is the tremendous difference in surface areas between sinter and group 3 fines iron ore, the latter being 89,000 sq cm per g, while highest surface area for sinter was on sample A with 3500 sq cm per g. Lowest area for sinter was 800 sq cm per g for sinter sample N.

The true or particle density of the material is also obtained with the B.E.T. equipment. As given in Table IV, the densest samples were found to be $L_1$ (5.09 g per cc) and $L_2$, while the lightest sample was sinter J (3.70 g per cc).

*Porosity Test:* An evaluation was made of the S.K. porosity test for determining porosity of sinter. Test equipment and procedures were adapted from those used by the Oliver Iron Mining Div. laboratories of

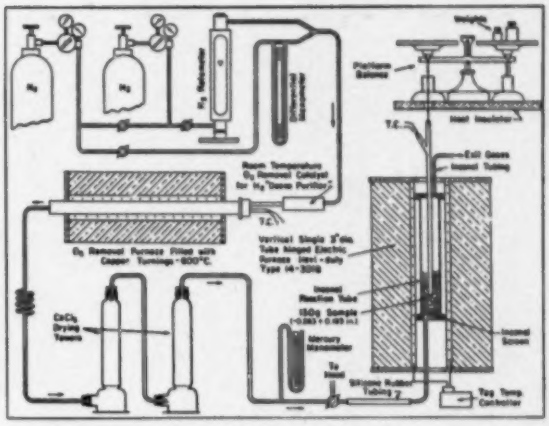

Fig. 2—A diagram of the hydrogen reducibility apparatus. The reducibility test was conducted at 800°C for 90 min, and loss in weight measurements were taken at intervals of 5 to 10 min. Temperature in the reaction chamber was then raised to 1000°C and reduction continued for 1 hr. Throughout reduction hydrogen flow rate was fixed at 0.124 cfm.

U. S. Steel Corp.[10] This test was originally developed in South Kensington, England, at the Imperial College of Science and Technology.[11] The test apparatus, illustrated in Fig. 3, measures the following properties of sinters: 1—Bulk density, grams per cubic centimeters. 2—Total porosity, percent, volume occupied by helium. 3—Macro porosity, percent, volume occupied by mercury at atmospheric pressure which penetrates pores in excess of +14 micron size. 4—Micro porosity, percent and cubic centimeters per gram, difference in volume occupied by helium and mercury at atmospheric pressure. This value is a measure of the −14 micron pores. 5—Particle density, grams per cubic centimeter, substantially identical to the true density obtained by the B.E.T. surface area measurement.

Table IV. Surface Area Measurements of Plant Sinters by the B.E.T. Method, Liquid Nitrogen Adsorption

| Sinter | Specific Surface, Sq Cm Per G | Comparative Order* Specific Surface | True Density, G Per CC | Comparative Order* True Density |
|---|---|---|---|---|
| A | 3500 | 1 | 4.17 | 7 |
| B | 250 | 10 | 4.36 | 6 |
| C | 2000 | 5 | 4.17 | 7 |
| D | 2400 | 4 | 4.14 | 7 |
| E | 700 | 8 | 3.91 | 9 |
| F | 2900 | 2 | 4.17 | 7 |
| G | 600 | 9 | 4.53 | 4 |
| H | 770 | 8 | 4.11 | 7 |
| I | 3300 | 1 | 4.29 | 6 |
| J | 100 | 10 | 3.70 | 10 |
| $L_1$ | 500 | 9 | 5.09 | 1 |
| $L_2$ | 530 | 9 | 5.02 | 1 |
| M | 300 | 10 | 4.60 | 4 |
| N | 80 | 10 | 4.60 | 4 |
| O | 790 | 8 | 4.28 | 6 |
| P | 1400 | 6 | 4.16 | 7 |
| Q | 1200 | 7 | 4.40 | 5 |
| Open hearth | 930 | 8 | 4.74 | 3 |
| Swedish sinter | 200 | 10 | 4.72 | 3 |
| Group 3 fines ore | 89000 | Very high | 4.35 | 6 |

* High value, 1; low value, 10.

Table V summarizes results of the S.K. porosity test on the plant survey sinter samples. Values are discussed in a later section of this paper.

*Davis Tube Magnetic Test:* It has been felt by many investigators that the degree of oxidation is an important factor in determining strength and reducibility of sinters. An evaluation was made of a

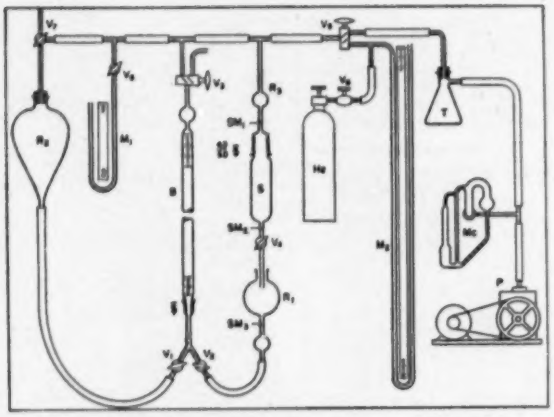

Fig. 3—The S.K. porosity testing apparatus shown above measures bulk density of sinters; total porosity, percent; macro porosity, percent; micro porosity, percent and cubic centimeters per gram; and particle density, grams per cubic centimeter.

Davis tube magnetic tester which magnetically separates the magnetic particles in a −100 mesh sample. The sinter with the highest percentage of magnetic material as given in Table VI was sample M with 94.3 pct; lowest values were obtained with sinter C, 65.6 pct, and Swedish sinter, 67.0 pct. The percentage of magnetic fraction consists not only of magnetite but other magnetic fractions as well, including some physically bound pieces of non-magnetic material. Magnetic measurements were not made on group 3 fines ore.

*X-ray Diffraction Analysis:* X-ray diffraction analyses of all the plant survey sinters were made to determine relative amounts of magnetite and hematite in each sample. Table VI gives the results obtained by X-ray diffraction. Prior to obtaining these values, the X-ray crystallographers prepared a curve of percentages of hematite and magnetite vs relative line intensities using physical mixtures of cp-grade hematite and magnetite. The X-ray technique used consisted of determining the relative intensities of $Fe_2O_3$ and $Fe_3O_4$ lines on a Debye-Scherer photographic negative obtained when the samples were radiated with Fe K $\alpha$ radiations. Therefore results in Table VI are actually iron oxide distributions. In assessing the degree of oxidation of magnetite to hematite, relative amounts of each in the total iron oxide content are of interest. Seventy percent of the iron oxide in Swedish sinter occurs in the form of hematite, an extremely high percentage. The highest percentage of iron oxide as hema-

## Table V. S. K. Porosity Test of Plant Sinter Using Mercury and Helium

| Sinter | Bulk Density, G Per CC | Comparative Order* | Total Porosity, Pct | Comparative Order* | Macro Porosity, Pct† | Comparative Order* | Micro-Porosity‡ Pct | Micro-Porosity‡ Comparative Order* | Particle Density, G Per CC |
|---|---|---|---|---|---|---|---|---|---|
| A | 1.49 | 4 | 63.8 | 8 | 58.8 | 8 | 5.0 | 2 | 4.12 |
| B | 1.40 | 5 | 67.0 | 6 | 63.8 | 6 | 3.2 | 6 | 4.22 |
| C | 1.36 | 6 | 67.9 | 6 | 62.4 | 6 | 5.5 | 2 | 4.26 |
| D | 1.50 | 4 | 64.5 | 8 | 60.5 | 7 | 4.0 | 4 | 4.20 |
| E | 1.68 | 1 | 59.6 | 10 | 56.6 | 9 | 3.0 | 6 | 4.15 |
| F | 1.29 | 7 | 68.9 | 5 | 65.4 | 5 | 3.5 | 5 | 4.20 |
| G | 1.55 | 3 | 65.9 | 7 | 62.3 | 6 | 3.6 | 5 | 4.55 |
| H | 1.40 | 5 | 66.7 | 6 | 61.2 | 7 | 5.5 | 2 | 4.14 |
| I | 1.56 | 3 | 63.3 | 8 | 58.4 | 8 | 4.9 | 3 | 4.23 |
| J | 1.12 | 10 | 69.3 | 5 | 66.8 | 4 | 2.5 | 7 | 3.62 |
| $L_1$ | 1.22 | 8 | 75.9 | 1 | 72.9 | 1 | 3.0 | 6 | 5.08 |
| $L_2$ | 1.17 | 9 | 76.6 | 1 | 74.0 | 1 | 2.6 | 7 | 5.00 |
| M | 1.52 | 3 | 66.9 | 6 | 62.9 | 6 | 4.0 | 4 | 4.58 |
| N | 1.50 | 4 | 67.7 | 6 | 63.6 | 6 | 4.1 | 4 | 4.64 |
| O | 1.49 | 4 | 66.3 | 7 | 64.7 | 5 | 1.6 | 9 | 4.42 |
| P | 1.28 | 7 | 68.8 | 5 | 64.6 | 5 | 4.2 | 4 | 4.10 |
| Q | 1.35 | 6 | 68.7 | 5 | 65.8 | 5 | 3.0 | 7 | 4.33 |
| Open hearth | 1.70 | 1 | 64.1 | 8 | 59.4 | 8 | 4.7 | 3 | 4.73 |
| Swedish sinter | 1.32 | 7 | 71.9 | 3 | 70.8 | 2 | 1.1 | 10 | 4.70 |
| Group 3 fines ore | 1.43 | 5 | 66.2 | 7 | 53.2 | 10 | 13.0 | 1 | 4.23 |

* High value, 1; low value, 10.
† +14 micron.
‡ −14 micron.

## Table VI. Relative Amounts of Magnetite and Hematite in Plant Sinters

| Sinter | Davis Tube, Pct Magnetic | Comparative Order,* Pct Magnetic | X-Ray Diffraction: $\frac{Fe_3O_4}{Fe_2O_3 + Fe_3O_4} \times 100$ | X-Ray Diffraction: Ratio of Magnetite to Hematite, Pct | X-Ray Diffraction: Other (Probable) Compounds | X-Ray Diffraction: Comparative Order,* Ratio of Magnetite to Hematite, Pct |
|---|---|---|---|---|---|---|
| A | 76.5 | 7 | 79 | 3.76 | | 7 |
| B | 83.0 | 4 | 86 | 6.14 | | 4 |
| C | 65.6 | 10 | 70 | 2.33 | Few pct quartz | 9 |
| D | 74.3 | 7 | 77 | 3.35 | Few pct quartz | 7 |
| E | 85.0 | 4 | 86 | 6.14 | | 4 |
| F | 81.0 | 5 | 84 | 5.25 | 5 pct $Fe_xO$, 5 pct FeO | 5 |
| G | 80.2 | 5 | 82 | 4.56 | | 6 |
| H | 71.9 | 8 | 76 | 3.17 | Few pct quartz | 7 |
| I | 71.7 | 8 | 80 | 4.00 | | 6 |
| J | 75.1 | 7 | 85 | 5.67 | Few pct quartz | 4 |
| $L_1$ | 84.3 | 4 | 80 | 4.00 | | 6 |
| $L_2$ | 83.8 | 4 | 75 | 3.00 | | 7 |
| M | 94.3 | 1 | 90 | 9.00 | | 1 |
| N | 74.8 | 7 | 83 | 4.88 | | 5 |
| O | 88.9 | 2 | 85 | 5.67 | | 4 |
| P | 74.1 | 7 | 74 | 2.85 | | 8 |
| Q | 84.9 | 4 | 79 | 3.76 | | 7 |
| Open hearth | 93.8 | 1 | 88 | 7.33 | | 2 |
| Swedish sinter | 67.0 | 10 | 30 | 0.43 | | 10 |

* High value, 1; low value, 10.

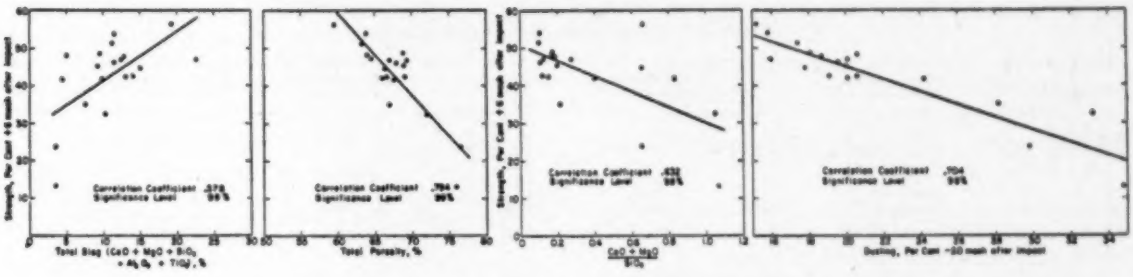

Fig. 4—Strength varies directly with total slag and inversely with slag ratio $\frac{CaO + MgO}{SiO_2}$, total porosity, and dusting.

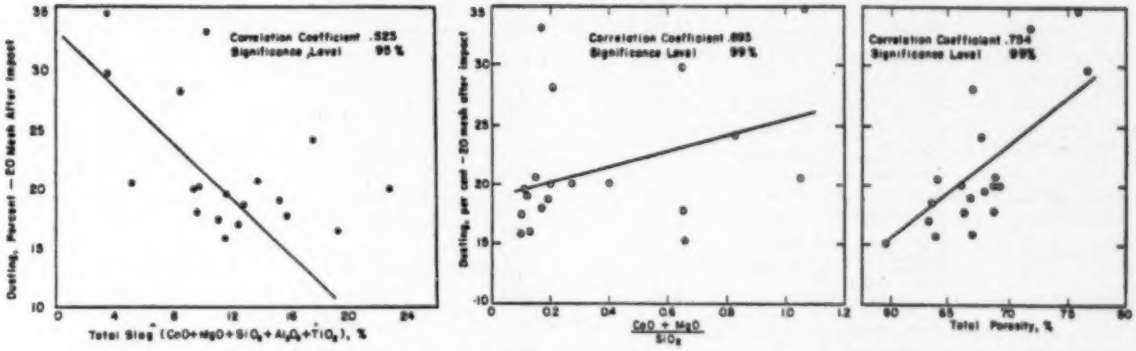
Correlation Coefficient .525
Significance Level 95%
Correlation Coefficient .695
Significance Level 99%
Correlation Coefficient .784
Significance Level 99%
Dusting, Percent — 20 Mesh After Impact
Total Slag (CaO+MgO+SiO2+Al2O3+TiO2), %
Dusting, per cent — 20 mesh after impact
CaO + MgO / SiO2
Total Porosity, %

Fig. 5—Dusting varies directly with slag ratio and total porosity but varies inversely with total slag. Relative reducibility, microporosity, FeO, and $Fe_3O_4$ are not related to strength and dusting.

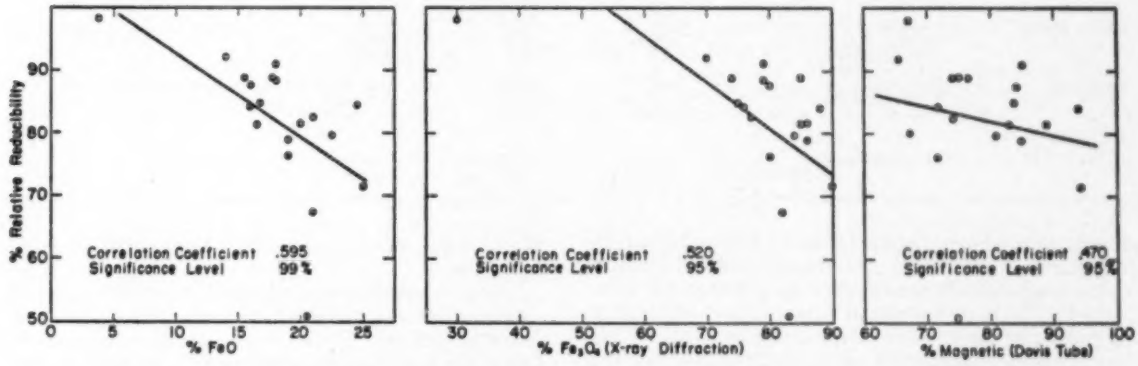


Fig. 6—Relative reducibility is inversely proportional to the Davis tube percentage magnetic, FeO, and $Fe_3O_4$ (X-ray), but it is not related to the slag ratio, total slag, strength or dusting. Relative reducibility is related directly to surface area. All measurements of the degree of oxidation of magnetite to hematite are directly proportional to each other, namely, FeO, $Fe_3O_4$ (X-ray), and Davis tube percentage magnetic.

tite in American sinter was 30 pct in sample C, the lowest 10 pct in sample M.

*Microstructure:* The study of the microstructure of sinters has been undertaken to identify constituents, determine the oxidation pattern, and formulate bonding theories. Although microstructure studies have been of great value, it was very difficult to arrive at a definite average structure for the sinter sample of each plant, since sinters are extremely heterogeneous.

*Slag Relationships in Sinters:* Table I indicates the slag ratio $\frac{CaO + MgO}{SiO_2}$ and total slag ($CaO + MgO + SiO_2 + Al_2O_3 + TiO_2$) of the plant sinter samples. Although FeO might have played an important role in affecting slag properties, its accurate determination in slag content of the sinters was an insurmountable problem at the time. According to Table VI only sinter sample F contained sufficient FeO to be detected by X-ray diffraction. None of the other samples contained sufficient FeO or slag phases containing FeO to be indicated by X-ray diffraction. The FeO, therefore, was not considered in these slag relationships. The range of the slag ratio obtained in the plant sinter samples was 0.099 to 1.065. Range in total slag was 3.47 to 22.60 pct.

*Correlation of Test Data:* Since many of the tests on plant sinters were believed to be measuring related properties as well as identical properties in the case of X-ray analysis and chemical analysis for FeO,

## Table VII. Correlation of Sinter Properties

| Property | Correlatable Property | Correlation Coefficient | Confidence, Pct | Proportionality Relationship | Non-Correlatable Property |
|---|---|---|---|---|---|
| Strength | Total porosity | 0.794 | 99.0 | Inversely | Microporosity |
| | $\frac{CaO + MgO}{SiO_2}$ | 0.632 | 99.0 | Inversely | FeO, pct |
| | Total slag | 0.578 | 99.0 | Directly | Relative reducibility, pct |
| | Dusting | 0.704 | 99.0 | Inversely | |
| Dusting | Total porosity | 0.754 | 99.0 | Directly | $Fe_3O_4$ (X-ray), pct |
| | $\frac{CaO + MgO}{SiO_2}$ | 0.693 | 99.0 | Directly | Relative reducibility, pct |
| | Total slag | 0.525 | 95.0 | Inversely | |
| | Strength | 0.704 | 99.0 | Inversely | Microporosity |
| Relative Reducibility, pct | Davis tube, pct Magnetic | 0.470 | 95.0 | Inversely | $\frac{CaO + MgO}{SiO_2}$ |
| | FeO, pct | 0.595 | 99.0 | Inversely | Total slag |
| | $Fe_3O_4$ (X-ray), pct | 0.520 | 95.0 | Inversely | Dusting, strength |
| | Surface area | 0.444 | 90.0 | Directly | Total porosity |
| Fe, pct | Particle density | 0.691 | 99.0 | Directly | |
| FeO, pct | $Fe_3O_4$ (X-ray), pct | 0.887 | 99.0 | Directly | Strength |
| | Relative reducibility, pct | 0.595 | 99.0 | Inversely | |
| | Davis tube, pct magnetic | 0.610 | 99.0 | Directly | |
| $Fe_3O_4$ (X-ray), pct | FeO, pct | 0.887 | 99.0 | Directly | Dusting |
| | Davis tube, pct magnetic | 0.619 | 99.0 | Directly | Surface area |
| | Relative reducibility, pct | 0.520 | 95.0 | Inversely | |
| Davis tube, pct magnetic | $Fe_3O_4$ (X-ray), pct | 0.619 | 99.0 | Directly | Surface area |
| | Relative reducibility, pct | 0.470 | 95.0 | Inversely | |
| | FeO | 0.610 | 99.0 | Directly | |
| Total porosity | Strength | 0.794 | 99.0 | Inversely | Surface area |
| | Dusting | 0.754 | 99.0 | Directly | Relative reducibility, pct |
| | $\frac{CaO + MgO}{SiO_2}$ | 0.458 | 95.0 | Directly | |
| | Total slag | 0.473 | 95.0 | Inversely | |
| Microporosity | Surface area | 0.503 | 95.0 | Directly | Dusting<br>Strength |
| Surface area | Microporosity | 0.503 | 95.0 | Directly | Total porosity<br>Relative reducibility, pct<br>$Fe_3O_4$ (X-ray), pct<br>Davis tube, pct magnetic |
| $\frac{CaO + MgO}{SiO_2}$ | Strength | 0.632 | 99.0 | Inversely | Relative reducibility, pct |
| | Dusting | 0.693 | 99.0 | Directly | |
| | Total porosity | 0.458 | 95.0 | Directly | |
| Total slag | Strength | 0.578 | 99.0 | Directly | Relative reducibility, pct |
| | Total porosity | 0.473 | 95.0 | Inversely | |
| | Dusting | 0.525 | 95.0 | Inversely | |
| | Correlation coefficient | 0.5751 | 0.5285 | 0.4555 | 0.3887 |
| | Confidence, pct | 99 | 98 | 95 | 90 |

it was decided to calculate correlation coefficients using standard statistical procedures. In these calculations two tests were compared by treating their results to determine significant linear relationships. Only results of the 19 plant sinter samples were used in the statistical calculation, since group 3 fines iron ore was used as a base line, and in many instances its properties were outside the normal spread of values for sinters. Table VII presents the correlation coefficients obtained by use of a formula from Ezekiel.[13] In Table VII each correlation coefficient is further clarified by presentation of the level of significance of the value or the confidence limit.[13] As an example of this significance, if a correlation coefficient has a numerical value equal to or higher than 0.4555 (95 pct significant) but lower than 0.5285 (98 pct significant) for a comparison of two properties, it is 95 pct certain that a relationship exists between the two properties.

To illustrate further the significance of the relationships uncovered by statistics, test data were plotted in Figs. 4, 5, and 6. To determine the *line of best fit* through the plotted data, the *method of least squares*[14] was employed. This straight line was plotted through the data, expressing an empirical relationship where estimates of the dependent variable (ordinate) may be made according to the linear function for any value of the independent variable (abscissa).

Using the statistical procedures outlined, a list of relationships was revealed between pairs of several sinter properties. These relationships, presented in Table VII and Figs. 4, 5, and 6, may be summarized as follows.

1—Strength varies directly with total slag and inversely with slag ratio $\frac{CaO + MgO}{SiO_2}$, total porosity, and dusting. Dusting varies directly with the slag ratio and total porosity but varies inversely with total slag. Relative reducibility, microporosity, FeO and $Fe_3O_4$ are not related to strength and or to dusting.

2—Relative reducibility is inversely proportional to the Davis tube percentage magnetic, FeO, and $Fe_3O_4$ (X-ray), but it is not related to the slag ratio, total slag, strength or dusting. Relative reducibility is related directly to surface area. All measurements of the degree of oxidation of magnetite to hematite are directly proportional to each other, namely, FeO, $Fe_3O_4$ (X-ray), and Davis tube percentage magnetic.

3—The total iron percentage is directly proportional to the particle density.

4—Surface area is directly proportional to microporosity and relative reducibility, but surface area and microporosity are not related to any other property statistically appraised.

## Discussion of Results

In a discussion of test results in plant survey sinters, the inadequacy of sampling based on a 400-lb grab sample of sinter at only one period must be taken into account. Furthermore, since there is no assurance that representative samples were secured, no comparisons can be made between the plant sinters. The important results of the experimentation were the development of test methods and the fact that a marked differentiation could be made between sinters of such varying compositions. It is hoped that some plants will be sufficiently interested in results of the tests reported to apply these methods in production trials on their sinters. Such trials, combined with blast-furnace production and operating data, would be of value in establishing requirements for good sinter in the blast-furnace.

From the viewpoint of a sinter plant operator, test results revealing strength, dusting, and relative reducibility would be of primary importance. Fortunately an increase in strength accompanied decrease in dusting; consequently the two can be considered together (from Table VII and Figs. 4, 5, and 6) as being related to total porosity, total slag, and the slag ratio, $\frac{CaO + MgO}{SiO_2}$. This information may be interpreted as follows: the slag ratio and total slag content control the total porosity, which in turn determines strength and dusting. With increasing slag content and decreasing slag ratio (more acid), a low porosity results. With low porosity, the strength is dependent upon a large cross-sectional area available to fracture and is therefore high. With high porosity resulting from an increasing slag ratio (approaching neutral) and a decreasing slag content, the cross-sectional area available to fracture is small and the strength is low. In summary, a high strength is obtained with highly acid slags and sufficient slag content to coat over the particles, thereby causing low porosity. Therefore, if this interpretation is correct, the sinter plant operator may control strength by controlling the slagging constituents.

In considering reducibility of the sinter, the sinter plant operator would be interested in the degree of oxidation of magnetite to hematite. With increasing magnetite in the sinters, reducibility was decreased; with increasing hematite content in the sinters reducibility was increased. The outstanding example of this is the Swedish sinter sample, which had a very high hematite content and resultant high reducibility. However, one fact is thought-provoking, namely, the lack of correlation between strength and reducibility or strength and degree of oxidation. Other investigators[35] have indicated correlations between strength and reducibility. Perhaps the fact that sinter samples used for this evaluation were produced under widely divergent conditions and from a variety of raw materials explains this lack of correlation between strength and reducibility.

## Conclusions

Nineteen sinter samples and one iron ore sample have provided a broad evaluation of test methods used to determine chemical and physical properties. The following factors were determined from the evaluation.

1—Impact test results of strength and dusting were related to total porosity, which was explained in terms of a slag ratio $\frac{CaO + MgO}{SiO_2}$ and the total slag content. With highly acid slag and high total slag, strength of sinter produced was high.

2—Relative reducibility test results were influenced by the degree of oxidation of sinter. The chemically analyzed FeO percentage provided the most significant correlative test.


## Acknowledgment

Thanks are extended to all the companies and their blast-furnace personnel for supplying production data and sinter samples for this evaluation. Thanks are also due the American Iron & Steel Institute for sponsoring this research at Mellon Institute and for permission to publish the results. The AISI Subcommittee on Agglomeration of Fines, under its chairman, E. G. Hill, greatly assisted in organizing the plant survey in 1949 and has been generous of time and advice while the tests were being developed and data collected.


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# A Guide to the Proper Application of Classifiers

by H. W. Hitzrot

SEPARATING a mixture of particle sizes of material suspended in a liquid medium is by no means an exact science. Selecting machines for individual classifying operations is even more difficult. The plant operator's own background is of course invaluable, and considerable help may be obtained from technical articles, talks with sales engineers, and handbooks on ore dressing. These several sources of information, however, are difficult to marshal in proper perspective for the major decision on classification units that an operator may be called upon to make. To the present writer's knowledge this assembly of facts is not available in handbooks, and technical papers are scarce on classification equipment developed in the past five or six years. It is believed that this paper will be helpful to users of classification equipment at this particular period in the development of hydro-classification.

For easy reference the following classification units now available and in use in metallurgical and industrial operations are listed below, with a brief description of each.

*Unit-type classifiers, bowl classifiers,* and *bowl desiltors* are all rectangular tanks, slightly tilted, with reciprocating rakes or screws to remove settled sands. The unit-type classifier, Figs. 1 and 2, is available in widths from 14 in. to 20 ft and lengths up to 40 ft. The shallow bowl of the bowl classifier, Fig. 3, equipped with rotating rakes, is superimposed on the lower end of the tank. Reciprocating rake compartments for this design range from 18 in. to 20 ft wide. Bowl diameters vary from 4 to 28 ft. The flat-bottomed bowl of the desiltor, Fig. 4, of relatively large diameter, is equipped with rakes rotating outward and partly over a pit, which is created by extension of the rectangular tank into and under the bowl section. Bowl desiltors are available with reciprocating rake sections 4 to 20 ft wide and bowls from 20 to 50 ft in diam. The bowl desiltor is used for applications beyond the range of the bowl classifier.

The *hydroseparator,* Figs. 5 and 6, is a circular tank equipped with slowly rotating rake arms, set on a slope, with interrupted rake or spiral blades to move the settled solids to a central discharge cone. Tank diameters vary from 4 to 250 ft. Tank depths at center are 2 to 3 ft for small units and up to 25 ft for larger units.

*Hydraulic classifiers* of the sizer and super-sorter types, Figs. 7 and 8, are narrow, deep, rectangular tanks divided by vertical baffles into a series of pockets. Hydraulic water is added near the bottom of each pocket. Perforated constriction plates, spiral flow arrangements, or jets are used to disseminate the water under pressure (hydraulic water) throughout the bed of material in the pocket. Discharge valves on each pocket are operated automatically by a pneumatic mechanism, a pincer-type mechanism, or a pressure control and motor combination actuated by a hydrostatic tube within the pocket. Hydraulic classifiers are available in 4, 5, 6, and 8-pocket units of varying constriction plate areas to suit conditions. There is now a jet sizer of unit pocket design that can be made up in 1 to 25 sections or more to accommodate sizing requirements.

The *hydroscillator,* Fig. 9, is a rectangular tank set on a slope of 3 to 4 in. per ft. A bowl is superimposed on the lower end. The bowl bottom is an oscillating rubber-covered disk, perforated to allow hydraulic water introduced beneath the disk to set up a teeter bed and thus produce an oversize or rake product exceptionally free of slimes, and material minus the mesh of separation.

A shallow dam at the periphery of the bowl allows the coarse or oversize fraction to spill over and drop down into the tank compartment, where it is moved up the deck by reciprocating rakes. The material, minus the mesh of separation, overflows a circular and stationary weir which is several inches higher than the dam on the oscillating disk. It is carried off in a circular launder in the usual manner.

These units are available in bowl diameters from 4 to 14 ft and with reciprocating rake compartment widths to suit the tons per hour to be handled.

*Centrifugal classifiers* include the solid bowl centrifuge and the cyclone classifier. The *solid bowl centrifuge,* Fig. 10, consists of a truncated cone fixed to a horizontal shaft and rotating at high speed. An internal spiral rotating at slightly less speed continuously removes solids deposited on the inner surface of the cone, or bowl.

Feed enters the cone by means of the hollow center shaft. Overflow leaves through ports at the large end of the cone, and oversize solids, moved by the spiral, exit through ports at the small end.

Centrifugal classifiers of this type are available in cone diameters from 18 to 54 in.

The *cyclone classifier,* Fig. 11, is a stationary cone having a cylindrical upper section and a lower cone section. Feed is introduced tangentially into the upper cylindrical section under pressure from a hydrostatic head or by means of a pump. Centrifugal force thus induced effects a classification within the cone, the fine sizes being carried off in the overflow through an opening at the top of the cylindrical section. Coarse solids at relatively high pulp density exit through a control valve at the apex of the lower cone section. Cyclone classifiers are available in 3, 6, 12, 14, 24, and 30-in. diam.

The *cone classifier,* Fig. 12, is a steel-plate cone with sides usually about 60° from horizontal. It contains no rotating mechanism. Feed enters a feedwell at center and classification is effected by gravity and pulp density. Fines are carried off in the flow over a peripheral weir at the top of the cone. Settled solids exit through an opening at the apex. An apex valve actuated through levers and rods by the pulp density in the lower cone section is usually supplied. Diameters are usually maximum at 8 ft.

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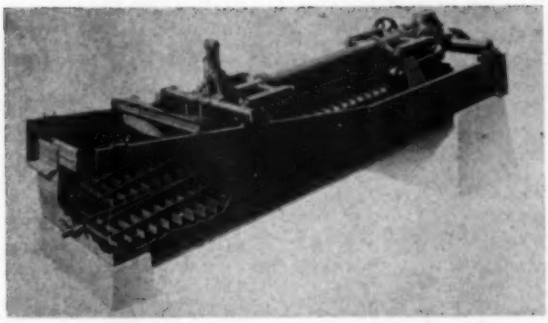


Fig. 1—A unit-type classifier utilizing reciprocating rakes.

Fig. 2—A unit-type classifier utilizing a continuous spiral.

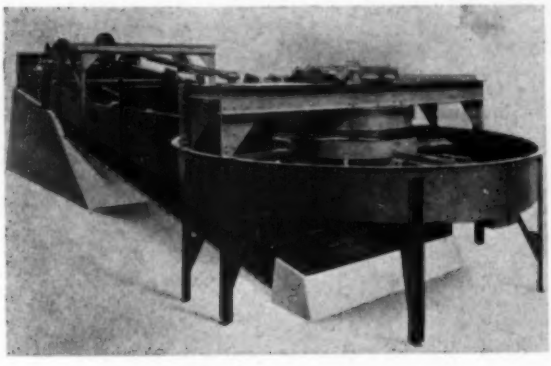


Fig. 3—The bowl-type classifier.

Fig. 4—A typical bowl desiltor installation.

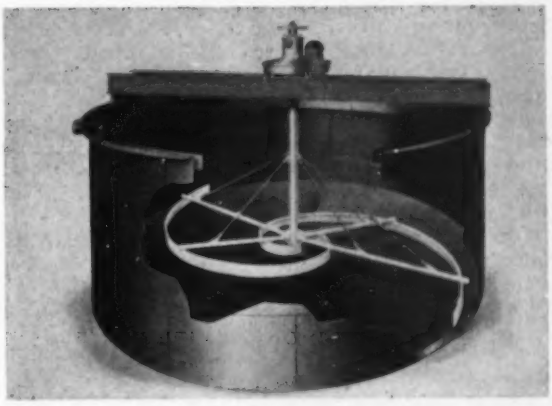


Fig. 6—The hydroseparator, showing spiral blade construction.

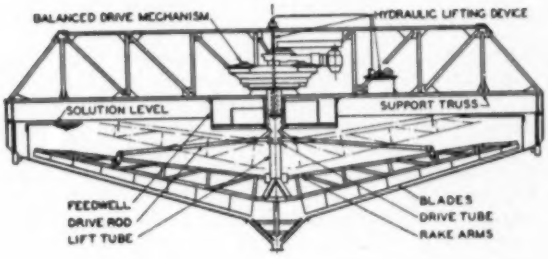



Fig. 5—Illustrative sectional elevation of hydroseparator utilizing interrupted rake blades.

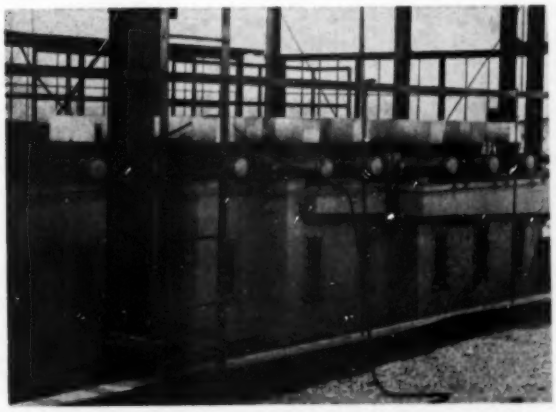


Fig. 7—Installation view of a sizer hydraulic classifier.

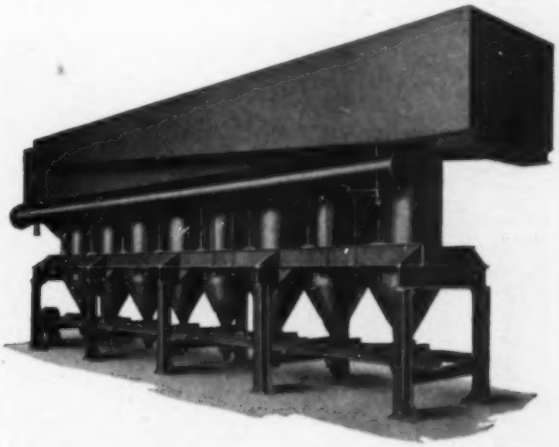


Fig. 8—A super sorter hydraulic classifier.

In the *sand washer*, Fig. 13, a set of buckets is attached to a circular frame rotated slowly on an inclined deck, which forms the bottom of a circular tank. The top of the tank side extending up from the heel becomes the overflow weir. Feed under pressure is introduced toward the center of the inclined bottom. Sand washers are available in 7, 9, and 12-ft diam.

Below what mesh of separation are classifiers more efficient than vibrating screens? Allowing for some latitude of opinion, 20 mesh is about the limit for a two-product separation on a mixed-size material of 2.65 sp gr. For separations coarser than 20 mesh, for example, 10 or 14 mesh, screens are preferable. On mixed-size materials having greater specific gravities, in the range of 3.5 to 5.0, classifiers should be limited to a separation at 28 to 35 mesh. Screens will be more efficient and should be used on two-product separations for 20 mesh and coarser.

Particles coarser than 20 mesh can be made to report in the overflow from unit-type classifiers when the ground ore or material contains a high percentage of true slimes. Such materials are cement rock and ores containing talc and clay. But these coarse particles, sometimes as large as ¼ in., are more in the nature of tramp oversize carried in suspension in a high-density classifier pool. The basic mesh of separation is more nearly at 20 mesh.

In hydraulic classifiers of the *sizer* and *supersorter* types it is possible to make a split at 6 or 8 mesh, but this is done at the expense of about 4 tons of hydraulic water per ton of feed handled and generally would not be practicable for big tonnage operation.

So much for the limitations of mechanical-hydraulic and centrifugal classifiers in general. For each of the nine types of classifiers described in this paper there are individual limits of application, as shown in Table I.

Mechanical-hydraulic classifiers, equipped with either reciprocating or spiral rakes, are the most widely used and have countless applications.

### Unit-Type Classifiers

*Limitations:* Unit-type classifiers are commonly employed for two-product separations, overflow and rake product, with overflow solids ranging between 20 and 100 mesh. Maximum size of feed particle is normally 1 in., occasionally 1½ to 2 in. When specific gravity of the feed solids is 4.0 to 5.0, overflow should be limited to a top size of 28 to 35 mesh.

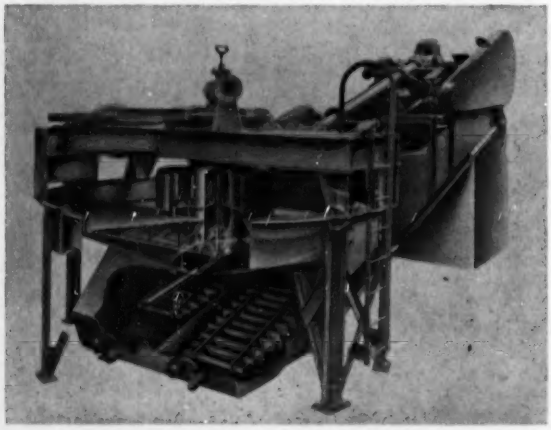
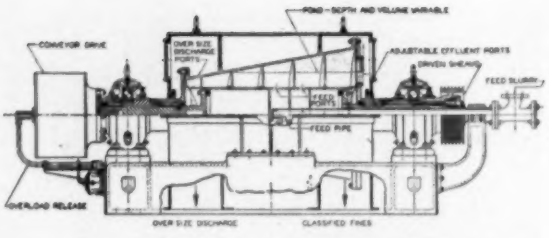


Fig. 9—A cutaway view of the hydroscillator.



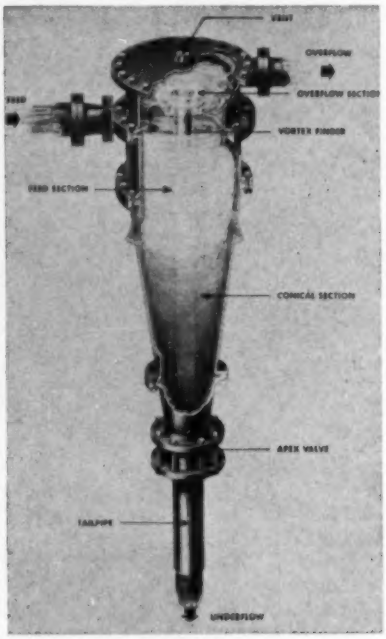




Fig. 10 (above)—A sectional elevation of the solid bowl centrifuge.

Fig. 11 (right)—Cutaway view of a cyclone classifier.

Control of water into these classifiers is very important, as separation at whatever mesh, 35, 48, 65, or 100, is made largely by the buoyancy or viscosity of the mixture of water and solids in the pool. Agitation of the sand-raking mechanism also affects mesh of separation. Excess water, contrary to the opinion of the uninitiated, ruins the separation by allowing too many particles of the desired size to drop down into the rakes or screws. Too little water, conversely, allows oversize particles to remain in suspension and contaminate the overflow.

When unit-type classifiers are used for scrubbing and dewatering, however, the amount of water entering with the feed is not critical. In most cases the products handled are preponderantly granular and hence fast-settling in character, for example, concentrates and silica sand. The pool area then determines the amount of water that can be handled. Fresh water in the form of wash water is frequently added up on the drainage deck section further to clean the rake product of contaminating slimes.

In both reciprocating and screw types, this classifier produces a rake product of consistent moisture content hour in and hour out, even with some variations in the feed volume. On dewatering operations carried out before further processing this is of great advantage. For instance, in the dewatering of phosphate rock prior to oiling ahead of tabling or prior to the addition of flotation reagents, the content of consistent low moisture solids in the rake product is highly valued.

*Applications:* Unit-type classifiers are used most frequently with mills for closed-circuit grinding of

Table I. Sizes, Limitations, and Major Applications of Unit Classifiers, Bowl Classifiers, Bowl Desiltors, Hydroseparators, Hydraulic Classifiers, Hydroscillators, Centrifugal Classifiers, Cone Classifiers, and Sand Washers

| Type of Classifier | Normal Size Range | | | Mesh of Separation, Ranges | Relative Classifier Efficiency | Normal Feed, Tonnage Range | Max. Oversize Handled | Normal Overflow, Pct Solids, Range | Normal Feed Density Range, Pct | Normal Underflow or Rake Product, Pct Solids | Motor Range, HP | Hydraulic Water Required | Typical Applications |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Width | Diam | Max. Length | | | | | | | | | | |
| Unit Classifier | 14 in. to 20 ft | — | 40 ft | 20 to 100 | Medium | 1 to 350 tph | 1 to 1½ in. | 5 to 65 | Not critical | 80 to 83 | ½ to 25 | Spray wash optional | Closed circuit grinding<br>Washing and dewatering<br>Process feed control |
| Bowl classifier | 18 in. to 20 ft | 4 to 28 ft | 38 ft | 65 to 325 | Medium plus | 1 to 300 tph | ½ to ¾ in. | 5 to 25 | Between 10 and 75 | 75 to 83 | Bowl: 1 to 7½<br>Recip. rakes: 1 to 25 | Water added with feed or in classifier for correct overflow density | Closed circuit grinding, usually in secondary circuit but sometimes in primary. Washing and dewatering |
| Bowl desiltor | 4 to 16 ft | 20 to 50 ft | 38 ft | 100 to 325 | Medium | 5 to 250 tph | ½ in. | 1 to 15 | Not critical | 75 to 83 | Bowl: 1 to 10<br>Recip. rakes: 5 to 25 | Spray wash optional | Recovery of fine sand, limestone, coal and fine phosphate rock from large flow volumes. |
| Hydroseparator | — | 4 to 250 ft | — | Usually 100 to 325. Special cases 35 to 325 | Low | Few lb per hr to 500 to 700 tph | ¼ in. | 1 to 20 | Not critical Generally 5 to 20 | 30 to 50 | Fractional to 15 | All water enters with feed | For fine separation where large feed volumes are involved |
| Hydraulic classifiers<br>Sizer | Varies with no. of pockets | — | Varies with no. of pockets | 6 to 150 | High | 2 to 100 tph | ⅛ to 3/16 in. | 5 to 20 | 40 to 60 | 40 to 60 | 1 to 2 for air pressure | Up to 4 tph feed | Gravity concentration of metallic ores<br>Preparation of table feed<br>Sizing of homogeneous materials |
| Super sorter | 6 ft | — | About 40 ft | ¼ to 150<br>¼ to 150 | High<br>High | 40 to 150 tph | ¼ to ⅜ in. | 5 to 20 | 30 to 60 | 40 to 60 | 1 to operate pincer valves | Up to 4 tph feed | Gravity concentration — preparation of table feed —coal<br>Sizing of homogeneous materials |
| Hydroscillator | 4 to 12 ft | 4 to 14 ft | 30 ft | 20 to 200 | High | 5 to 250 tph | ½ to 1 in. | 15 to 30 | 40 to 80 | 75 to 83 | Bowl: 3 to 10<br>Rakes: 5 to 20 | Up to 1.5 tph per ton of feed | Used where exceptionally clean rake sands are needed<br>Closed circuit grinding |
| Centrifugal classifiers<br>Cyclone | — | 3 to 30 in. | 9 ft | 100 mesh to 5 microns | Medium | 10 to 1500 gpm | 14 to 20 mesh | 5 to 30 | 1 to 30 | 55 to 70 | Power for pressure head | None | For fine separations in variety fields |
| Solid bowl centrifuge | — | 18 to 54 in. | 70 in. | 100 mesh to 5 microns | Medium plus | Up to 500 gpm | ¼ in. | 5 to 30 | 1 to 30 | 40 to 70 | 10 to 50 | None | For fine size fractionating down to 5 microns |
| Cone classifier | — | 2 to 12 ft | — | 28 to 325 | Low | Up to 100 tph | ¼ in. | 5 to 30 | Not critical | 35 to 60 | None | None | For desliming and primary dewatering |
| Sand washer | — | 7 ft<br>9 ft<br>12 ft | — | 28 to 65 | Medium | 25 to 125 tph | 1 in. | 5 to 30 | About 30 to 35 | 80 to 83 | 5 to 10 | None | For desliming and dewatering large tonnages of bulk material |

nonferrous and ferrous ores, cement rock, silica, and pigments. In fine grinding, straight classifiers are often used for single-stage grinding and as the primaries in two-stage grinding. Not infrequently they function as classification units in the secondary stage of two-stage grinding. As would be expected, the width of the unit to be selected depends on the 24-hr tonnage handled, the mesh of separation, and the specific gravity of the material.

Unit-type classifiers are also employed for final scrubbing, washing, and dewatering of granular products such as phosphate rock, ground silica, concrete sand, fine coal, limestone, precipitated alumina, and mineral concentrates from flotation and gravity concentration milling. Occasionally these classifiers size, wash, and dewater granular organic-chemical products in plastics and related fields.

Reciprocating rake-type units have wide application as grit-removal devices on *detritors*, which remove coarse solids in municipal sewage-disposal plants. They also function as grit and unburned core removal devices in continuous slaking of burned lime. These combination units are known as *slakers*.

Another application of reciprocating rake units is the washing of coarse ore: gold ores, bauxite, iron ores, and marls in cement-manufacturing processes. These units, called *washers*, are reciprocating rake classifiers with separately driven wire mesh or punched plate trommels superimposed over the pool end and partly submerged in it.

A machine of this type can produce three products: a washed coarse material about −3 in. from the trommel, a −⅜ or ½-in. rake product, and finally an overflow −48, 65, or 100 mesh to dust, all of which is carried off with the overflow water.

Employment of unit-type classifiers in the field of ore concentration by the heavy-media process is most worthy of mention. They are used as separatory vessels for both coarse and fine ore fractions. The screw or spiral-equipped unit is particularly applicable as a densifier unit: the screw can be lowered into a bed of heavy media (finely ground magnetite or ferro-silicon) and stored in the classifier pool. Density in the heavy-media circuit is thus periodically raised.

### The Bowl Classifier

*Limitations:* The bowl classifier has been designed and developed for separations finer than are generally attempted in the straight or unit-type classifiers. For the more usual 2.65 to 3.0 sp gr materials, a two-product separation at 65 mesh is the generally accepted top limit. Separations within the range of 100, 150, 200, and 325 mesh are, however, more common. The raking mechanisms of this unit can handle a feed containing particles as large as ½ to ¾ in. For materials of 3.5 to 5.0 sp gr, the top limit for a two-product separation with the bowl classifier is about 100 mesh, and because of the heavier gravity, fineness of separation can be extended below 325 mesh (43 microns) or down to about 20 microns (750 mesh).

At this time diameter of the bowl section does not exceed 28 ft. This limitation is imposed by design difficulties of balancing and rigidity for the overhanging rake section extending underneath the midpoint of the bowl and about 2 ft beyond it.

As with the unit classifiers, water entering the bowl classifier must be controlled. Whereas unit classifiers generally overflow at 25 to 40 pct solids, bowl classifiers overflow at 5 to 25 pct solids; the finer the mesh of separation, the lower the percent of solids in both unit and bowl classifiers.

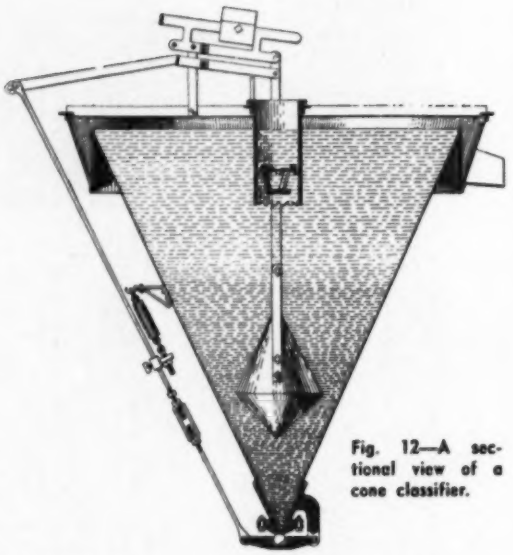


Fig. 12—A sectional view of a cone classifier.

A bowl classifier, when used in closed-circuit grinding, must handle a large tonnage of circulating sands in addition to the new feed. In such cases it is essential to equip the classifier with a reciprocating rake section of a width approximately 80 pct of bowl diameter. Thus for a 20-ft diam bowl the reciprocating rake section should be 16 ft wide, with four rakes 4 ft wide. Reciprocating rakes are standard in 2, 3, and 4-ft widths and an even number of rakes must be used. Hence a 15-ft diam bowl with reciprocating rake section 12 ft wide would have four rakes 3 ft wide.

*Applications:* The bowl classifier is used most commonly in the secondary or final grinding stage in the closed-circuit grinding of nonferrous and ferrous ores, cement rock and marls, silica sand, and pigments. It is less frequently used in the single-stage fine grinding of these same materials and in the regrind circuits for middlings and concentrates.

The bowl classifier also has wide application as a deslimer. This is by virtue of the fact that any water added into the reciprocating rake compartment has but one means of escape up through the opening in the bowl bottom. Solids collected in the bowl enter the reciprocating rake compartment through this same opening and lose much of their slimes and fines content in the rising stream.

### The Multi-Deck Washing Classifier

In some processing operations it becomes desirable to wash a contaminating chemical solution from the rake product of a bowl or a unit-type classifier. In most instances more than one washing stage is required, and one, two, or three additional raking sections are added in cascading fashion to make a unit-type or a bowl classifier with multidecks for the counter-current washing of the sand product. Fresh water is added on the final deck and progresses downward counter-currently to movement of the solids. The wash water flows from one raking section to the next lower section by means of interconnecting launders.

Multi-deck washing classifiers have widest application in the chemical processing field for the counter-current washing of nickel compounds, chro-

mium ores and compounds, alumina, abrasives and abrasive intermediates, tri-sodium phosphate, zeolite sands, and some other chemical compounds. Acid-proof construction must be used for some operations.

### The Bowl Desiltor

*Limitations:* The bowl desiltor is a classification unit of fairly recent design and usage that bears some semblance to the old *Clabowl* used in the china clay and filler clay fields. Its use is limited to operations involving large flow volumes and fine separations where the former goes beyond the range of the maximum diameter (28 ft) of bowl classifiers, or where the relatively small amount of solids in the large volume of flow does not justify the heavy duty construction of bowl classifiers.

The bowl desiltor makes a two-product separation with the mesh of separation in 150 to 200 or 325 mesh range. Usually the tonnage of coarse or rake product is relatively small and more often than not, duplex rakes will handle it. This machine neatly combines in one unit the use of a hydroseparator for the fine separation and a unit-type classifier to dewater the dilute hydroseparator underflow.

The top size for the coarsest particles in the feed to this unit should not exceed ½ in. Certainly there would be few occasions when any solids coarser than about 6 mesh would be in the feed, but the rakes will handle a limited amount of ½-in. pieces.

*Applications:* At the present time the bowl desiltor has widest application in the recovery of extremely fine sand overflowing the various washing units in concrete sand, foundry sand, glass sand, and limestone-processing plants. Such recovered fine sand is delivered in a drained condition by the reciprocating rakes and is used as a special product or is blended into the coarser product to increase the fineness modulus.

It is conceivable that in the future the bowl desiltor will be used whenever it is desirable to remove a small amount of finely divided solids from a large volume of flow, that is, for the recovery of fine coal, phosphate sand, blast furnace flue dust, or fine mineral concentrates.

### The Hydroseparator

*Limitations:* In the hydroseparator a widening in the line of flow allows the coarser particles to settle out from the suspension. Only the cone classifier is simpler in construction. The hydroseparator is frequently misused because its limitations are not fully recognized.

Classification efficiency of the hydroseparator is appreciably lower than that of the unit-type and bowl classifiers. It depends entirely on gravity settling for the separation, and the overflow can be set to contain around 1 pct or less of particles plus the mesh of separation. This is done at the expense of allowing a relatively high separation of particles minus the mesh of separation to settle into the underflow, resulting in low classification efficiency. The underflow will always contain about 40 to 60 pct of the material minus the mesh of separation, the higher percentage being approached when coarse separations in the 35 to 65 mesh range are adopted.

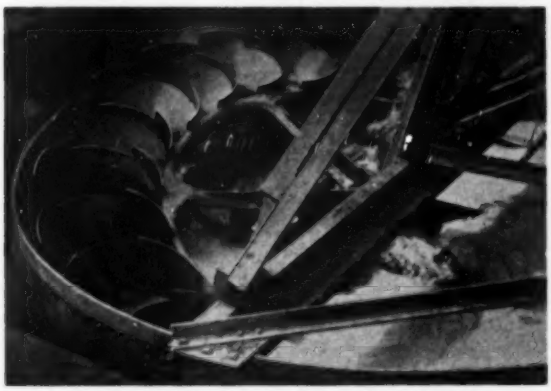


Fig. 13—Installation view of a typical sand washer.

The hydroseparator is generally used for separations finer than 100 mesh, except when the feed flow is so great that the cost of the multiplicity of bowl or unit-type classifiers required makes a coarse separation by means of a hydroseparator attractive. Feed to a hydroseparator should not contain particles much over ¼ in., and when there is an appreciable amount of 28 mesh to ¼-in. material present, as in concrete sand, then heavy duty mechanisms with arms at a slope of 2 to 3 in. per ft should be used.

There is no limitation on the handling of heavy-gravity material in hydroseparators, but the steep rake arm slopes mentioned above should be used.

The size or diameter of a hydroseparator is a function of the feed volume and the separation desired. The tonnage of solids to be handled does not directly affect the size but must be taken into account in selecting the design and height of raking mechanism. The tonnage handled can range from a few pounds up to 500 to 700 tons per hr.

*Applications:* The comparatively low classification efficiency of the hydroseparator restricts its use to situations where the volume of flow is beyond the range of unit classifiers, bowl classifiers, and the bowl desiltor. It is used, however, for small feed flow volumes where no great importance is attached to the poor classification feature.

The hydroseparator is appropriate when a large volume of water is to be sloughed off prior to further processing of the granular fraction, and units of 75, 100, and 150-ft diam are applicable. Under special conditions units of 200 to 250-ft diam might be used for such problems. Typical applications are the primary hydroseparation of phosphate rock matrix, primary dewatering and scrubbing of concrete sand or other silica sand products following wet screening, and recovery of fine coal in coal washing operations, both in the anthracite and bituminous fields. Further classification or dewatering of the granular solids settled in the hydroseparator is carried out in subsequent operations in all the above cases, so that the limited classification and dilute underflow of the hydroseparator are accepted because of its capacity to handle high flows.

In past years hydroseparators have been used to size abrasive products and to process clays and pigments and a variety of chemical precipitates. In view of the recent development of centrifugal classifiers and the bowl desiltor, it is the author's opinion that hydroseparation problems in the fields mentioned above will be solved in the main by these two types of classifiers.

### Hydraulic Classifiers: Sizers and Super Sorters

*Limitations:* All classifiers thus far discussed except the washer (unit-type) have been two-product machines, coarse and fine. Eight of the nine main types, in fact, are limited to two products.

The sizer and super sorter are multi-pocket units and, therefore, multi-product. Thus for any problem requiring more than two sizes of products from

one machine, the multi-pocket hydraulic classifier is the only one available. It is made up with varying constriction plate areas to meet tonnage requirements, and the number of pockets used depends on the range of products to be made and the weight distribution in the screen analysis of the feed.

Feed to any hydraulic classifier should not contain particles coarser than ¼ in., preferably not over ⅛ or 3/16 in. The classification pockets in series each served by hydraulic water under low pressure will each make a relatively clean size split combining roughly two screen sizes. That is to say, the first pocket on a −14 mesh feed will entrap practically all the +20 and a good part of the +28. The second pocket will entrap the remaining +28 with the bulk of the +35 and some of the +48, and so on down through the several pockets.

The −100, +150 mesh particles are about the finest that can be entrapped and cleaned free of the −150 with any degree of efficiency. Thus all particles −150 mesh will report in the overflow of the sizer and must be further provided for if they are to undergo additional classification or are to be saved.

All hydraulic classifiers operate best when receiving a fairly constant volume of feed somewhere between 40 and 60 pct solids. A unit-type classifier, particularly of the rake type, is ideal for feeding one or more sizers or super sorters.

Another limitation of hydraulic classifiers is the high moisture underflow discharge from each pocket, ranging from 40 to 60 pct solids. Frequently provision must be made for further dewatering.

The super sorter is made up with equal-sized pockets in line with mechanical pincer-type underflow valve controls actuated from a single drive. The latest design of *jet* sizer also is made up of equal-sized pockets, but they can be arranged in line or in pyramid as the underflow valves are actuated by an individual pneumatic control.

Hydraulic classifiers are widely used to prepare sized products for gravity concentration by means of tables or similar devices embodying free settling or hindered settling. This is the major application of sizers and super sorters.

An important field for this type of classifier is the beneficiation of iron, tin, titanium, tungsten, vanadium, chromium, zinc, and lead, and such nonmetallics as coal, phosphate rock, and silica sand. It should be mentioned at this point that the super sorter was especially designed as a high-tonnage unit for use in the cleaning of fine coal.

Another less prominent but increasingly significant field of application for sizers and super sorters is the separation of homogenous products into various size fractions. Natural silica sand is an example. Foundry and glass sands are sold according to grain sizes or grades, and concrete sands frequently require one or more size fractions.

In a few instances the sizer has been used to retreat smokeless powder and to size chemical compounds such as sodium aluminate crystals.

### The Hydroscillator

*Limitations*: Separation with the hydroscillator ranges between 20 and 200 mesh inclusive. That is to say, operating conditions can be set to overflow from the oscillating bowl 20 mesh at the coarse limit and at any mesh on down through 28, 35, etc., to 200. Coarse particles up to ½ or 1 in. in the feed can pass through the oscillator compartment without difficulty.

Hydraulic water at the rate of 0.5 to 1.5 tons per ton of feed is necessary to effect the highly efficient separation. For the required separation with a reasonable amount of hydraulic water, feed should be in the form of a thick slurry for separations in the coarser meshes. For separations in the finer meshes a dilute feed is permissible. The oversize fraction of the feed as delivered by the reciprocating rakes will be dewatered to 79 or 84 pct solids.

*Applications*: It is safe to say that the hydroscillator is applicable to any problem requiring a clean rake product with the minimum amount of hydraulic water. It is a relatively new development in mechanical-hydraulic classifiers, and the range of applications, limited at present, is being expanded. The hydroscillator is well established in the closed-circuit grinding of ores and minerals and is a unit of relatively high capacity. This is evidenced by the fact that at Tennessee Copper Co. a 10-ft diam hydroscillator handled the entire mill tonnage of 2200 tons per 24 hr and overflowed this tonnage at 2 pct +48 mesh and approximately 54 pct −200 mesh. It is also interesting to note that the rake product contained only 1.0 to 2.0 pct −200, as compared to 9.0 to 10.0 pct for the conventional classifier. It is further significant that the average percent oversize in the grinding mill was 81 pct for the hydroscillator, in contrast to 68 pct for the conventional classifier circuit.

Although the hydroscillator is more expensive, it will find increasingly wide application not only for closed-circuit grinding but also for sharp two-product separations in beneficiation of iron ore and processing silica sand, to name but two of the prominent fields. A classifier that decreases the amount of undersize remaining in the rake product from the 130 tons left by the conventional classifier to 24 tons is bound to have many applications.

### Centrifugal Classifiers

*Limitations:* 1—The solid bowl centrifuge. This unit can develop centrifugal forces up to 1000 times gravity, and with such characteristics it is the only commercial unit that will accomplish reasonably efficient separations down in the low micron range. Ordinarily the solid bowl centrifuge is limited to relatively fine separations from about 100 mesh to as low as 5 microns.

When the solid bowl centrifuge is used for dewatering, it cannot be expected to give a complete split of water and solids; the very fine material will be carried out with the overflow. In this connection it must also be kept in mind that as the removal of fines with the spiral product is increased the amount of moisture in this product will also increase, as it will in any of the mechanical-hydraulic classifiers. The feed volume must be kept to conservative proportions: the largest unit, 54x70 in., is limited to about 500 gpm.

2—The stationary cone or cyclone classifier. In this type of classifier the centrifugal force is set up by injection of the feed tangentially under pressure. Pressure is generally maintained at 15 to 20 psi but is raised up to as much as 80 to 100 psi when extremely fine separations are necessary.

The cyclone, having a steep-angle cone section of 20°, is in its present design usually limited to separations between 147 microns (100 mesh) on the coarse side and 10 to 20 microns on the fine side. It is limited in that abrasive action of any appreciable amount of coarse particles in the feed causes excessive wear when high pressures are used.

The stationary cone classifier, like the bowl centrifuge, will not have a clear overflow as long as slimes are present in the feed. A completely granular feed devoid of slimes would permit clear overflow, but such conditions are rare.

It is well to keep in mind that both the cyclone and the solid bowl centrifuge classify at heavy feed densities as compared to any of the other types employing an open pool for classification.

Larger diameter units favor the coarser separations, i.e., the 100 to 150 mesh range, whereas small diameter units are preferred for separations from 150 mesh to 10 microns.

The percent of solids in the feed has little effect on the underflow density, which will range from 55 to 70 pct, depending on the screen analysis fineness range. The finer the material, the lower the percent of solids.

An indication of capacity is a figure of 1000 to 1200 gpm for the 24-in. diam cone when it makes a 150-mesh separation on a material of 2.7 sp gr.

*Applications:* The stationary cone type of centrifugal classifier is applicable in a wide variety of fields. Undoubtedly it will be preferred in some cases that would require a large hydroseparator, since a combination of cones would eliminate the need for a large tank. There is good evidence of this in the phosphate rock washing operations in Florida.

As intimated above, the stationary centrifugal cone classifier is now accepted as a good primary deslimer. This simple centrifugal classifier has been launched in several other directions which appear to be promising: fine silica sand recovery, beneficiation of low-grade iron ores, and preparation of concentrator mill tailings for mine backfill.

### The Cone Classifier

*Limitations:* An inverted cone with feed entering a centrally located feedwell at the top, the overflow spilling over the outer rim and the underflow discharging at the apex, makes a very simple classification device. Since no provision is made for scraping settled solids from the inside surface of the cone, a steep angle, 60° to 75°, must be used to minimize deposition. Hence the vertical clearance just about equals the diameter, and this may well become a disturbing factor when cones 8 to 12 ft in diam are called for. Probably the most common top size of cone is 8 ft in diam, but units of 10 to 12-ft diam have been installed.

The cone classifier, like the hydroseparator, provides only a quiescent pool for settling solids, and, as would be expected, effectiveness of classification is of low order, approaching closely that of hydroseparator. It is no secret that the operation of cone classifiers is sensitive to the character of feed solids. Any material containing fine particles having a tendency to adhere to a sloping side will build up on the sides of the cone, often plugging it entirely.

The cone works best when fed a solids mixture containing a high percentage of truly granular material which will scour the sides. With this kind of feed, dense underflows in the range of 40 to 60 pct solids can be maintained by any of a number of restricted apex discharge arrangements. The operation under dense underflow conditions is frequently critical. To prevent plugging the practice is to maintain free-flowing discharge at 35 pct solids.

There is practically no limitation on the size range of solids that can be handled in a cone classifier. Classification should not exceed 28 mesh on the coarse side and about 325 mesh on the fine side. Large feed volumes will require a multiplicity of units, thereby imposing some problems for equal feed distribution.

*Applications:* The cone classifier has one big advantage over the other types in that it is cheaper in first cost and comparatively cheap to install. It uses no power and maintenance is low. On materials of highly granular character it can serve as a primary classifier or dewaterer.

With the improvements in mechanical-hydraulic classifiers, there are no longer many fields in which cone classifiers are extensively used. In the production of concrete sand they are frequently used to sort and dewater small flows of specialty products, the cones being located over bins or storage piles. There are also a number of applications for cone classifiers in certain industrial processing operations handling relatively small volumes of feed flow.

### The Sand Washer

*Limitations:* The sand washer, with its circular line of buckets dipping into the settling pool of a round tank, is a rough and ready unit that thrives on big tonnage. As a classifier it has narrow limitations separation-wise, owing to the pool area afforded by the design.

The sand washer should not be selected for separations except between the range of 28 mesh on the coarse end and 65 mesh on the fine end. It can be used on a feed mixture containing particles as coarse as 1 in. and by special arrangement up to 1½ to 2 in. Ordinarily the feed size range to a sand washer is ¼x0 in., which is typical of a concrete sand, but the buckets can be designed to handle the coarse sizes mentioned.

Capacity limitation for the 12-ft diam unit is about 125 tons per hr of bucket product when a 48-mesh separation is made on material of 2.65 sp gr. This capacity necessitates a feed at 2 to 1 dilution or 33 1/3 pct solids. In other words, the 12-ft sand washer is limited to about 1000 gpm overflow when making a 48-mesh separation.

The washed product as it is discharged from the buckets will contain 17 to 20 pct moisture (83 to 80 pct solids). This product can be handled on an inclined belt conveyor without creating a backwash down the belt.

Under the same conditions of feed and overflow the 7-ft and 9-ft diam sand washers are limited to 25 to 35 tons per hr and 45 to 65 tons respectively.

*Applications:* Sand washers, as the name implies, have been used almost exclusively for removal of silt and clay from banks and from natural sand deposits under water. The usual flowsheet involves screening the several sizes of gravel with the final —¼-in. sand plus all the water, silt, and clay being directed to the sand-washing and dewatering device. If the sand washer is used, some provision must be made, such as a settling box, to slough off sufficient water to maintain the feed to the sand washer at 2 to 1 dilution or 30 to 35 pct solids.

There is little promise of a wide range of application for the sand washer type of classifier. It is possible, however, that it could be used for high tonnage sand slime separations in mining operations, particularly in the disposal of tailings.

It can be seen that there is much overlapping of functions and that limitations cannot be clearly defined. More often than not information is relative and comparative. It should be emphasized again that classification is not an exact science.

# Milling Kentucky Fluorspar Tailings

by LaMont West and Robert R. Walden

KENTUCKY'S first acid-grade fluorspar flotation mill, shown in Fig. 1, was placed in operation Aug. 1, 1952, by the Pennsylvania Salt Manufacturing Co. at Mexico, Ky. During 1951 a critical shortage of acid-grade fluorspar developed and it became necessary for the company to produce part of its fluorspar requirements.

In 1951 the company purchased the Crider and Lennen metallurgical fluorspar mill and an adjacent stockpile of tailing at Mexico, Ky. The tailing, assaying about 26 pct calcium fluoride, originated from log washer and jig mill concentrators in the area. As the mill did not have a fluorspar dryer or convenient rail facilities, the company leased the Burleson concentrator at Marion, Ky., where these facilities were available. At Marion, Ky., on the Illinois Central Railroad, dry acid-grade fluorspar is transported direct to the company's Calvert City, Ky., hydrofluoric acid plant.

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The Mexico flotation plant was reconditioned and designed to produce acid-grade fluorspar from the jig tailing stockpile. The new plant flowsheet is shown in Fig. 2.

The ore feed, old tailing, which contains 10 pct of waste rock and coarse gravel assaying approximately 8 pct $CaF_2$, is bound together by sticky clay slimes and at first presented a problem in ore handling. A typical screen analysis and assay of the tailing is recorded in Table I. Study of the analysis

**Table I. Screen Analysis of Kentucky Fluorspar Tailings**

| Screen Size, Mesh | Pct | $CaF_2$ | $SiO_2$ | $CaCo_3$ | $R_2O_3$ |
|---|---|---|---|---|---|
| On ½ in. | 10.02 | 8.14 | 40.66 | 50.03 | 1.17 |
| On 20 | 3.28 | 18.07 | 38.86 | 37.80 | 5.47 |
| On 40 | 3.20 | 28.00 | 32.38 | 32.42 | 7.20 |
| On 60 | 3.43 | 34.83 | 33.40 | 27.78 | 3.99 |
| On 80 | 3.75 | 38.76 | 35.27 | 22.44 | 3.53 |
| On 100 | 4.81 | 45.35 | 31.61 | 19.31 | 3.73 |
| On 150 | 6.52 | 48.91 | 31.04 | 17.76 | 4.29 |
| On 200 | 7.98 | 45.42 | 29.69 | 17.14 | 7.75 |
| On 325 | 8.02 | 40.38 | 36.24 | 15.32 | 8.06 |
| Through 325 | 48.99 | 18.12 | 53.32 | 13.67 | 14.89 |
| Stockpile ore | 100.0 | 26.04 | 43.32 | 21.62 | 9.02* |

* The 9.02 pct $R_2O_3$ includes 0.40 pct sulphur.

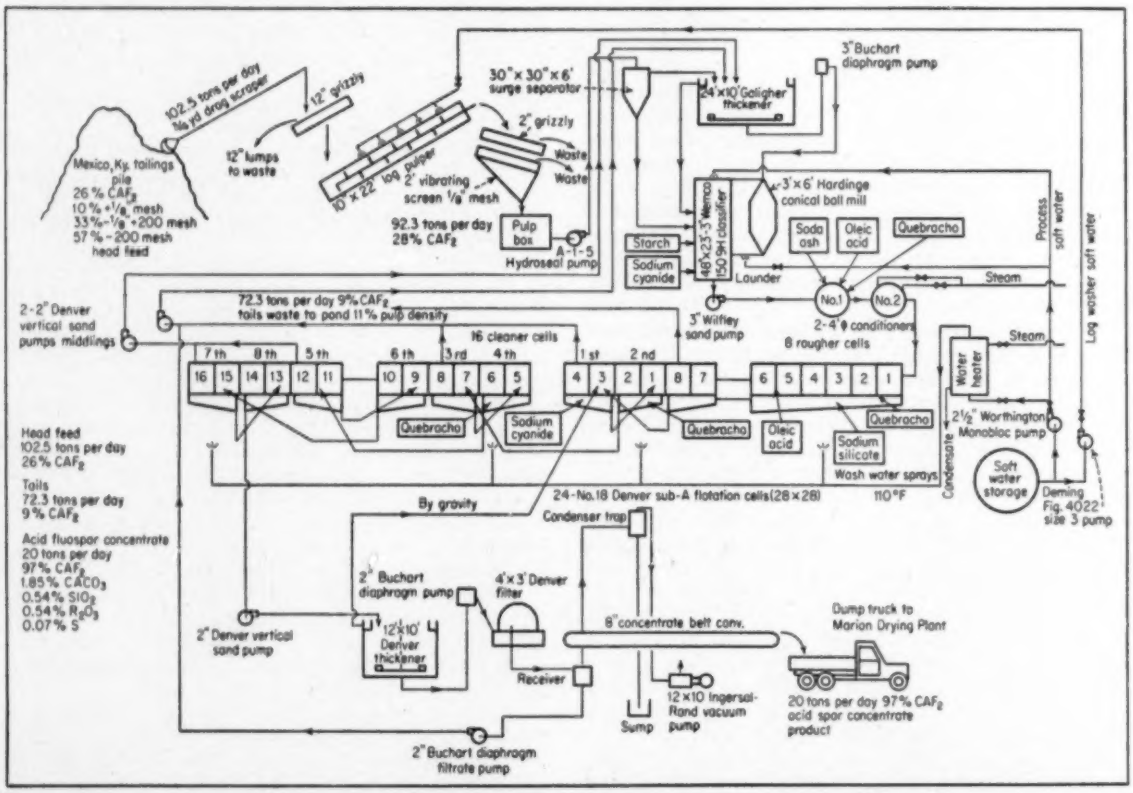
102.5 tons per day ¾ yd drag scraper
12" grizzly
Mexico, Ky. tailings pile
26 % CaF2
10 % +1/8" mesh
33 %-1/8" +200 mesh
57 % -200 mesh
head feed
12" lumps to waste
10' x 22' log washer
2' vibrating screen 1/8" mesh
Waste
Waste
92.3 tons per day 28% CaF2
Pulp box
A-1-5 Hydroseal pump
30" x 30" x 6' surge separator
2" grizzly
54' x 10' Galigher thickener
3" Buchart diaphragm pump
3' x 6' Hardinge conical ball mill
46" x 25'-3" Menzies 150 SH classifier
Soda ash
Oleic acid
Quebracho
Starch
Sodium cyanide
Launder
Process soft water
Steam
No.1
No.2
2-4' ϕ conditioners
8 rougher cells
3" Wilfley sand pump
72.3 tons per day 9% CaF2 tails waste to pond 11 % pulp density
2-2" Denver vertical sand pumps middlings
16 cleaner cells
7th 8th 5th 6th 3rd 4th 1st 2nd
16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 8 7 6 5 4 3 2 1
Quebracho
Sodium cyanide
Quebracho
Oleic acid
Quebracho
Sodium silicate
Wash water sprays
Water heater
Steam
Log washer soft water
2½" Worthington Monoblac pump
Soft water storage
Deming Fig. 4022 size 3 pump
Condensate
Head feed 102.5 tons per day 26% CaF2
Tails 72.3 tons per day 9 % CaF2
Acid fluospar concentrate 20 tons per day 97% CaF2 1.85% CaCO3 0.54% SiO2 0.54% R2O3 0.07% S
By gravity
24-No.18 Denver sub-A flotation cells (28 x 28)
110°F
Condenser trap
2" Buchart diaphragm pump
4' x 3' Denver filter
8" concentrate belt conv.
Dump truck to Marion Drying Plant
2" Denver vertical sand pump
12' x 10' Denver thickener
Receiver
12 x 10 Ingersol-Rand vacuum pump
Sump
20 tons per day 97% CaF2 acid spar concentrate product
2" Buchart diaphragm filtrate pump

Fig. 1—A diagram of the acid-grade fluorspar flotation mill at Mexico, Ky.

suggested that the ore could be conveyed readily by pumping if it were slurried and screened to re-

**Table II. Representative Screen Analysis of Classifier Overflow**

| Screen Size, Mesh | Pct |
|---|---|
| On 20 | 0.09 |
| On 60 | 0.26 |
| On 100 | 0.21 |
| On 150 | 3.17 |
| On 200 | 13.18 |
| −200 | 83.08 |
| Composite | 100.00 |

move the +⅛ in. size, which is relatively barren of calcium fluoride.

Ore is pulped at 30 to 40 pct solids in a single log washer. Pulp overflows at the sand discharge-end through a 2-in. grizzly, then through a 2-ft Denver-Dillon vibrating screen with ⅛-in. mesh

**Table III. Screen Analysis of Classifier Return Sands**

| Screen Size, Mesh | Pct |
|---|---|
| On 10 | 17.75 |
| On 20 | 16.68 |
| On 60 | 19.41 |
| On 100 | 19.68 |
| On 150 | 15.69 |
| On 200 | 6.00 |
| −200 | 4.79 |
| Composite | 100.00 |

wire cloth into a sump. The screen oversize is removed with a belt conveyor. A bulldozer daily removes the grizzly oversize and the belt discharge. A 3-in. hydroseal dredge-type pump moves the pulp to a surge cone. The surge cone discharges directly to a 48-in. No. 150 S.H. Wemco spiral classifier. The raw feed entering the classifier, which has been upgraded by screening off the oversize, assays about 28 pct $CaF_2$.

The density of the overflow from the classifier is maintained at from 15 to 17 pct solids. A characteristic screen analysis of the classifier overflow is given in Table II. Normally the circulating load of the grinding circuit is about 150 pct; Table III shows the screen analysis of the classifier return sands.

Ball-mill feed consists of classifier return sands and underflow from the flotation middling thickener. The middling thickener overflow constitutes part of the classifier makeup water. Analysis of the flotation middlings is given in Table IV.

The ball mill density, maintained at more than 60 pct solids, is controlled by the density of the feed from the middling underflow.

There are twenty-four No. 18 28x28-in. Denver Sub-A cells in the flotation circuit. The rougher consists of eight cells and there are eight stages of cleaners, consisting of two cells each. The cleaner cells are lined up in four groups of four cells each, arranged to effect two cleaning stages and to produce one middling to each group.

The plant produces approximately 20 tons of acid fluorspar concentrate daily, with recovery of approximately 76 pct. The analysis of the concentrate is recorded in Table V.

A 60-mesh stainless steel wire filter cloth on the concentrate filter resulted in an excessive loss of fines and an 80-mesh cloth was substituted to alleviate this condition. The original plant used a screw conveyor for wet filter cake handling; however,

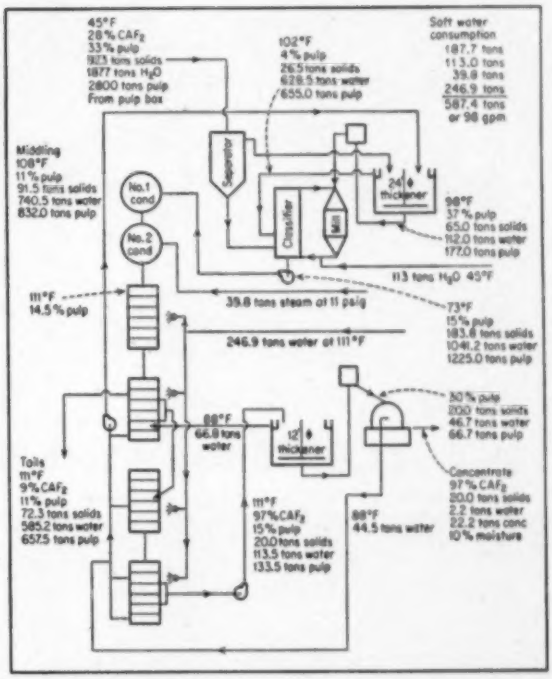


**Fig. 2—The flowsheet for the reconditioned plant at Mexico, Ky.**

maintenance was so great that it was replaced with a belt conveyor.

The acid spar concentrate after drying at the Marion, Ky., plant is bone dry. The 5-ft diam x 30-ft direct oil-fired rotary dryer was found to be very satisfactory when operating at temperatures slightly under 500°F. The dryer was completely lined with 4½-in. fire brick to cut down external heat radiation.

**Table IV. Analysis of Flotation Middlings**

| Screen Size, Mesh | Pct | $CaF_2$, Pct | $SiO_2$, Pct | $CaCo_3$, Pct | $R_2O_3$, Pct | Fluorspar, Free or Attached, Pct |
|---|---|---|---|---|---|---|
| − 60 + 100 mesh | 0.21 | 55.87 | 12.18 | 25.74 | 6.21 | 0.002 |
| −100 + 150 mesh | 2.16 | 60.74 | 5.07 | 31.81 | 2.38 | 0.040 |
| −150 + 200 mesh | 15.32 | 56.40 | 4.89 | 35.36 | 3.45 | 0.000 |
| −200 + 325 mesh | 51.56 | 52.90 | 8.28 | 32.80 | 6.02 | 0.000 |
| −325 | 30.75 | 56.60 | 11.88 | 26.93 | 4.59 | 0.000 |
| Composite | 100.00 | 55.66 | 7.91 | 31.47 | 4.96 | 0.042 |

Water for the plant, obtained principally from local mines and from a drilled well, has a hardness of approximately 19 grains per gal. Recovery and

**Table V. Analysis of Acid Fluorspar Concentrate**

| Item | Pct |
|---|---|
| Screen analysis | 91.99 (−200 mesh) |
| Calcium fluoride | 97.02 |
| Calcium carbonate | 1.85 |
| Silica | 0.54 |
| $R_2O_3$ | 0.53 |
| Sulphur | 0.06 |

grade of concentrate were unsatisfactory and a 200-gpm Zeolite water softener was installed. All water now utilized in the process is dead soft as indicated by the soap test.

The pulp in the rougher cells is maintained at a temperature of 110° to 112°F and is controlled by a

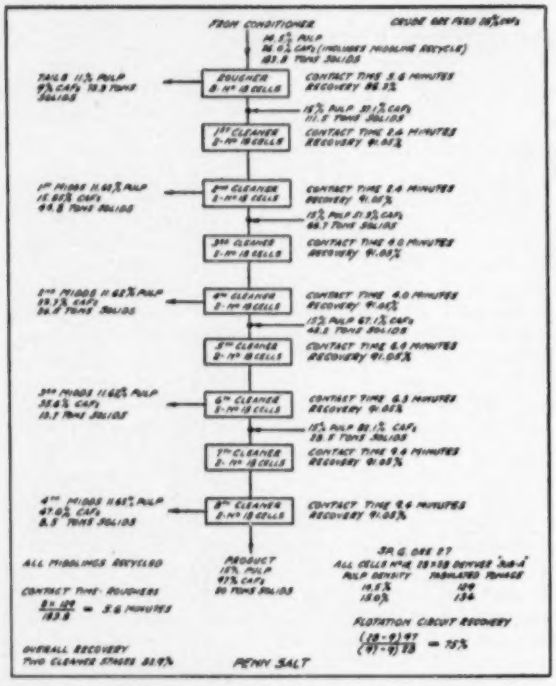


**Fig. 3—Approximate concentrations, pulp densities, and contact time in the flotation cells as calculated. Note that the ratio of middlings is approximately 1 to 1.**

direct injection of steam into the No. 2 conditioner. This temperature is also maintained throughout the flotation circuit by means of launder wash water at 110°F.

The classifier overflow being fed to the No. 1 conditioner is maintained at 15 to 17 pct solids, depending upon the quality of the stockpile ore being fed. The wide variation in the stockpile ore requires grinding changes (fineness) to liberate the calcium fluoride. This in turn requires a corresponding change in the classifier overflow and in the flotation cell densities.

A typical daily material balance is shown in Fig. 3. It should be noted that the ratio of middlings recycled to the feed is approximately 1 to 1. Fig. 4 shows the approximate concentrations, pulp densities, and contact time throughout the flotation cells. Data are calculated from actual operation.

## Reagents

The flotation reagents used per ton of head feed are shown in Table VI. Inasmuch as the ore contains from 1 to 2 pct sulphides, sodium cyanide is fed into the classifier to depress the sulphides. The amount, approximately 0.4 lb of cyanide per ton of head feed, has been determined to be essentially correct for the ore being processed. If more cyanide than this amount is used, the pH increases, causing control of the pH by soda ash further on to become very critical, the flotation froth is toughened, and the sulphide content of concentrate is not further reduced.

Causticized starch is also fed to the classifier to depress silica. In preparing causticized starch to insure a colloidal suspension of the starch, a 1 to 1 ratio of starch to caustic is used. The starch is made up with a small amount of hot water and the caustic is added and stirred for several minutes before its dilution with hot or warm water. The caustic which is fed in association with the starch stabilizes flotation and renders the final pH control by the soda ash less critical.

Soda ash is fed into the No. 1 conditioner at a rate to maintain pH between 8 and 8.5. The No. 1 conditioner is also fed 0.3 lb of quebracho, 0.1 lb of sodium silicate, 0.5 lb of oleic acid, and a small amount of Pentasol No. 26 frother. These reagents are used to depress the calcite and silica and to act respectively as a flotation collector and frother for the calcium fluoride.

Sodium silicate and quebracho are also fed to the rougher concentrate at the rates of 0.1 and 0.2 lb, and 0.1 lb of oleic acid is fed as required into the overflow between the No. 5 and No. 6 rougher cells. Quebracho is fed as needed, 0.1 to 0.2 lb, at two points equally distributed along the flotation cleaning circuits. Provision was made to feed sodium cyanide into the launder of the first cleaner stage as may be found necessary.

Regardless of how well the ore is mixed on the stockpile with a bulldozer, there are wide variations in the flotation characteristics of the ore. The amount of mine plant refuse, alluvial soil, and organic material also varies considerably, rendering the ore most difficult to treat. For these reasons, it has not been possible to set operating conditions for more than a week at a time. Classifier densities and the quantities of depressants must be altered to meet the changing conditions.

**Table VI. Flotation Reagents Per Ton of Head Feed**

| Reagents | Lb Per Ton |
|---|---|
| Oleic acid | 8 to 14 |
| Quebracho | 0.4 to 0.6 |
| Starch | 0.7 |
| Starch | 0.5 |
| Sodium silicate | 0.4 to 0.5 |
| Sodium cyanide | 0.3 to 0.4 |
| Caustic | 0.5 |

When either the silica or the calcium carbonate become too difficult to hold within the concentrate specifications, the blend from the stockpile is changed.

## Operation

During the initial weeks of operation, the total head feed was thickened and fed directly to the ball mill to repolish the mineral surfaces. This was believed necessary because the feed consisted of tailings that had been exposed to weathering conditions. The procedure actually increased metallurgical difficulty. Capacity was low and recovery below 65 pct, and it was difficult to maintain concentrate grade.

When the process was changed to that of directly feeding the classifier, with only the coarse sands going to the ball mill together with the recycled middlings, the metallurgy smoothed out and capacity was increased.

A more recent curative measure has been to cut out the No. 1 middlings and impound for remilling at a later date. This procedure enables the circuit to be bled of silica, which has a tendency to build up in the system.

## Acknowledgment

The authors have endeavored to pass on experience gained in the design and operation of an acid-grade fluorspar flotation plant operating on log washer sands and jig mill tailings. They acknowledge gratefully the assistance of the plant personnel during preparation of this article.

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R. E. O'Brien, 808 Newhouse Bldg., Salt Lake City, Field Secretary

C. M. Cooley, Mining Branch Secretary



# Industrial Minerals Div. Eyes Lake Placid and Salt Lake City

The list of subjects to be covered at the Rocky Mountain Region Industrial Minerals Conference is shaping up in an impressive manner. The meeting will be held October 29 and 30, with registration scheduled for October 28.

Among the papers to be presented will be ones covering industrial minerals required to produce iron and steel at the Geneva steel works; titanium; electric furnace production of elemental phosphorus; industrial water; natural gas; and mining of phosphate rock and of gypsum.

The Rocky Mountain Region, Industrial Minerals Div. includes Montana, most of Idaho, Wyoming, Utah, Colorado, Arizona, New Mexico, Oklahoma, and western Texas. It is reported that Nevada is interested in joining the Region.

One of the outstanding social events of the meeting will be Industrial Minerals Luncheon, October 29.

### Fall Meeting

Industrial Minerals Div. members planning on attending the fall meeting October 5 to 9, at Lake Placid, N. Y., had better dust off the old Brownie box camera and pack along a lot of film. Lake Placid in the fall is the shutterbug's idea of heaven.

The Lake Placid Chamber of Commerce calls fall "the flaming leaves season." The foliage erupts into a riot of color, the mountain air is crisp and clean, and the nights endowed with a kind of silence found only in the woodlands.

Lake Placid encircles a chain of three islands, Buck, Moose, and Hawk. Homes on the islands can be reached only by boat. The island arrangement makes for an outstanding course for motor and sail boat races. The visitor can choose his own level of athletic endeavor—be it horseback riding, fishing, hunting, hiking, mountain climbing, boating, skeet or trapshooting, archery, baseball, bicycling, or milder forms such as shuffleboard, horseshoes, table tennis, pool, or croquet. For the adventurous, water skiing offers thrills.

**Lake Placid, where the Industrial Minerals Div. is slated to hold its Fall Meeting, is situated on two lakes, not one. Mirror Lake is in the foreground and Lake Placid in the background. The area offers almost every summer sport, even summer ice skating, to its visitors.**

One of the more noteworthy attributes of Lake Placid is the promise it gives of a good night's sleep to hay fever sufferers. The resort is about 2000 ft above sea level. Divot diggers will find the Craig Wood Golf and Country Club keeps its fairways in excellent playing condition. Early fall visitors can also enjoy warm weather ice skating in the heart of the village. Speckled, brown, and rainbow trout offer the seasoned angler a worthy challenge. Gunners will find an open season on raccoons, and the squirrel season is generally from October to November. Grouse, partridge, pheasants, waterfowl, and woodcock are plentiful in the fall.

Details of the technical program, which is to include both papers and field trips, will appear in MINING ENGINEERING as plans unfold.

## Final Annual Meeting Attendance Figures

| Function | Attendance |
|---|---|
| Registration | 3521 |
| Welcoming Luncheon | 1311 |
| Smoker | 1336 |
| Informal Dance | 422 |
| Banquet | 1790 |
| Mining Dinner | 225 |
| MIED Supper | 149 |
| Scotch Breakfast | 220 |
| MBD Luncheon | 164 |
| MGGD Luncheon | 276 |
| Mining and Metallurgical Society of America Luncheon | 163 |
| Coal Luncheon | 120 |
| MIED Luncheon | 40 |
| Ind. Min. Div. Luncheon | 116 |
| Yale Alumni Luncheon | 36 |
| MED Luncheon | 17 |

## Around the Sections

• The **Tri-State Section** meeting at Baxter Springs, Kan., heard Sim S. Clarke, general superintendent, Tri-State Mines Div., Eagle-Picher Co., describe the Annual Meeting in New York last February, and he was persuaded to show the Section the Saunders Medal he received at that meeting. George A. Komadina, assistant superintendent, central mill, Eagle-Picher Co., reviewed his paper, *Comparison of Ferrosilicon Recovery*, first presented at the Annual Meeting. Philip Jones and Ken Nobs were among the leaders of a lively discussion on sink-float ore dressing technique.

• The **Birmingham, Ala., Section** is scheduling a social meeting to be held May 15. The All-Section meeting was held at Decatur, Ala., recently. L. C. Fuller, Shell Oil Co., speaking at the March gathering, discussed *The Oil Industry*.

• The **Alaska Section** held its Annual Banquet with 225 persons filling the dining room to capacity. The section also sponsored the open house which marked the official opening of the new Territorial Dept. of Mines Bldg. Ernest N. Patty, president of the University of Alaska, speaking at the dinner, said, "Someday, if we keep pounding away, the powers that be in Washington are going to give us some tax incentive laws. Laws which will cause the major mining companies to return to Alaska and give Alaska the same attention they are now giving to Canada."

• *Application of the Air-Borne Magnetometer to Ore Prospecting*, was the topic presented to the **Lehigh Valley Section** by W. B. Agocs, Aero Service Corp., at the group's April meeting. On tap for May 7 is the Spring Dinner Dance at the Saucon Valley Country Club, Bethlehem, Pa., 8:00 pm. The section will visit Ingersoll-Rand Co., at Phillipsburg, N. J., in September.

• **The Utah Section,** meeting in Salt Lake City, heard Walter A. Dew, manager, Public Relations Dept., Du Pont Co., San Francisco, speak on *Things to Come in Chemistry*, at the April meeting. Big event for May will be the Spring Dinner Dance, featuring cocktails, dinner, floor show, and of course, dancing. The event is scheduled for the Newhouse Hotel. Later in the month, at the Student Section Meeting, members of the section will gather in the Geology Bldg. of the University of Utah. Topic of the meeting will be *Use of Geophysics in Solving Geologic and Mining Problems*, encompassed in a paper presented by Kenneth L. Cook, head of the Geophysics Dept. AIME President Leo F. Reinartz is expected to attend the stag set for late in September. Aim of the get-together is "fellowship and conviviality." The Rocky Mountain Region Industrial Minerals Conference is set for Salt Lake City October 29 and 30. Held for the first time, the conference will present three sessions. Following the meeting on Saturday afternoon, the University of Utah gridsters clash with the University of Idaho. The Fall Dinner Dance will climax the conference Saturday evening. November 18 will see the joint meeting of the Utah Section and the Intermountain Assn. of Petroleum Geologists. Granville S. Borden, Special Tax Counsel, Standard Oil Co. (of California), San Francisco, will present *Taxation and the Mineral Industry*.


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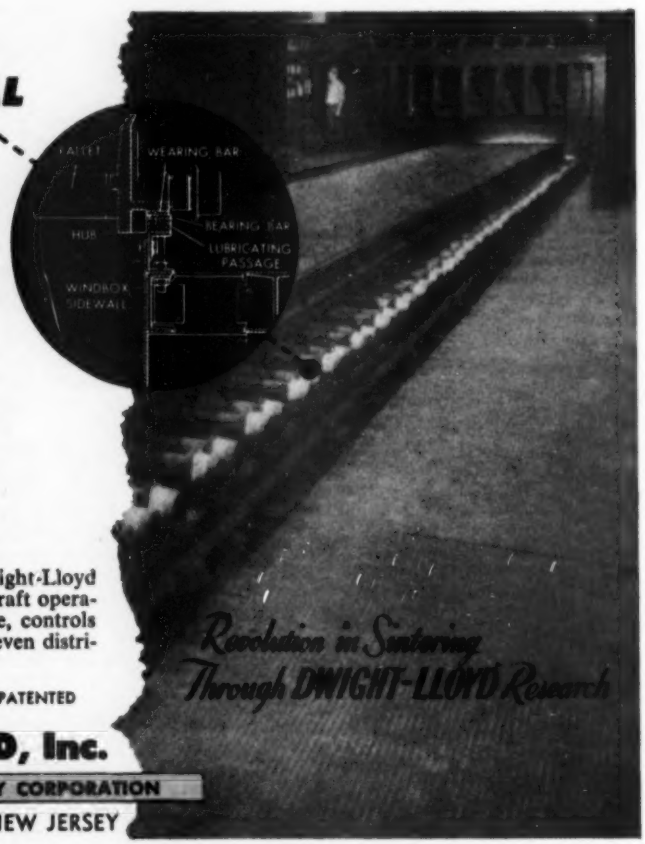


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## *Around the Sections*

• Ted Rizzi's description of *Aerial Prospecting for Uranium in the Northern Black Hills* at the March meeting of the **Black Hills Section,** met with approval of the 43 persons who attended. Gordon Mathisrud followed with a description of the Carlile uranium area in northeastern Wyoming. He also described the mining methods employed and how the depths of overburden and attitude of orebodies influenced them.

• J. Byrkit, smelter superintendent, arranged for movies of the Consolidated Mining & Smelting Co. operation at Trail, B. C., to be shown at a recent meeting of the **Ajo Subsection,** Ajo, Ariz. Mr. Gailbraith spoke to the section at another meeting on experiences in French Morocco with the Air Force Intelligence. He is currently with the Geology Dept. of the University of Arizona.

• First meeting of the year of the **Minerals Beneficiation Subsection, Minnesota Section** was held at the Coates Hotel, Virginia, Minn., April 21. Principal topic of the dinner meeting was the paper on *Depolarizing of Magnetite Pulps,* by Milton F. Williams and Luther G. Hendrickson, both of Oliver Iron Mining Div., U. S. Steel Co.

• Speaking before the **St. Louis Section,** Roblee B. Martin, Mississippi Lime Co. of Missouri, elaborated on problems confronted in maintaining separation of oolitic formations from basic lime deposits. He noted that major part of the tonnage of burnt lime produced by his firm is turned out in rotary kilns. Vertical kilns are used mainly for calcining lump lime used in open hearth furnaces.

• The **Southern Sierra Subsection** met recently in the Sierra Cafe, Lone Pine, Calif., to hear John F. Emerson, U. S. Vanadium Corp., discuss his company's mining methods.

• Howard's Cafe in Rock Springs, Wyo., was the scene of a meeting of the **Wyoming Section** not long ago. Charles E. Tonry, U. S. Bureau of Mines Oil Shale Experimental Station, Rifle, Colo., described the work of the station, accompanying his talk with color slides.

• *Techniques of Surface Grinding* **is a 16 mm color film just released by the DoAll Co. It explains operating techniques that assure control of dimensions, form, and finish in grinding. Information may be obtained from the company at 254 North Laurel Ave., Des Plaines, Ill.**

• **The National Safety Council's new series of human relation training films for foremen is now available. The series consists of three films:** *Fragile—Handle Feelings with Care, Call 'Em on the Carpet,* **and** *It's an Order.* **Films run 12 min and are available in 16 mm as well as 35 mm sound slides. Information and prices can be obtained from the council at 425 N. Michigan Ave., Chicago.**

• *No Margin for Error* **is a new sound-slide film in color which attempts to answer lubricating problems. Released by Alemite, a division of Stewart-Warner Corp., and running 15 min on 35 mm film, the sound-slide offers five plans on lubricant handling. The film and accompanying booklet are available from the nation-wide Alemite distributing organization.**


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## Pacific Coast Regional Clay Conference To Be Held June 25 and 26, Berkeley, Calif.

The 1954 Pacific Coast Regional Conference on Clays and Clay Technology is scheduled for the Berkeley campus of the University of California, June 25 and 26.

Subject of the conference will be the clay-water system. Papers on permeability of liquids through formations, swelling of clays, viscosity, and plasticity will be presented. Afternoon discussions will follow morning presentation of papers.

Co-sponsor of the conference is the Clay Minerals Committee of the National Research Council. Members of the committee arranging the conference are: George S. Gates, Petroleum Experiment Station, U. S. Bureau of Mines San Francisco; J. Schlocker, Engineering Geology Branch, U. S. Geological Survey, Menlo Park; Mort D. Turner, California State Div. of Mines, San Francisco. Members of the committee at the University of California are: Isaac Barshad and Walter P. Kelley, Dept. of Soils; Irving Goldberg, Institute of Transportation and Traffic; Alexander Klein, Div. of Civil Engineering, Charles Meyer and Adolph Pabst, Dept. of Geological Science; Wilbur H. Somerton, Petroleum Engineering; and Joseph A. Pask, Ceramics, Div. of Mineral Technology. Mr. Pask is committee chairman.

The General Electric X-Ray Diffraction School, also to be held on the Berkeley campus, precedes the conference, June 21 to 25.

## Institute Accepts Fairless Award Fund

The AIME has accepted a fund from U. S. Steel Corp. to be used for the Benjamin F. Fairless Award for distinguished achievement in iron and steel production and metallurgy.

The Award, an annual one, will honor the U. S. Steel chairman's interest in the technology and development of the iron and steel industry. The AIME now has distinguished achievement awards covering all major technical fields encompassed by the Institute, including mining, nonferrous metallurgy, petroleum finding or production, mining administration (defined broadly to include petroleum and metallurgy), coal mining, and minerals beneficiation.

Committees will work out details and choose the first recipient of the Benjamin F. Fairless Award. Its first presentation will be at the Annual Banquet of the AIME, Feb. 16, 1955, Conrad Hilton Hotel, Chicago.

## Awards For 1955 Listed

Authority has been voted for granting of the following awards in 1955.

Charles F. Rand Medal for mining administration; James Douglas Gold Medal for nonferrous metallurgy; Erskine Ramsay Medal for coal mining; J. E. Johnson, Jr., Award for pig iron metallurgy; Robert W. Hunt Medal for an iron and steel paper; Rossiter W. Raymond Award for best paper by an author under 33; Mathewson Gold Medal for physical metallurgy paper; and the newest honor, the Benjamin F. Fairless Award for achievement in iron and steel production and metallurgy.

For the first four awards, anyone may suggest an appropriate person to receive the honor but only a Member of the pertinent committee may nominate a candidate. The Secretary of the Institute will be glad to forward suggestions to the proper committee chairmen. Brief descriptions of the various awards were made in the 1952 AIME Directory and Year Book, pages xvii to xxiii.


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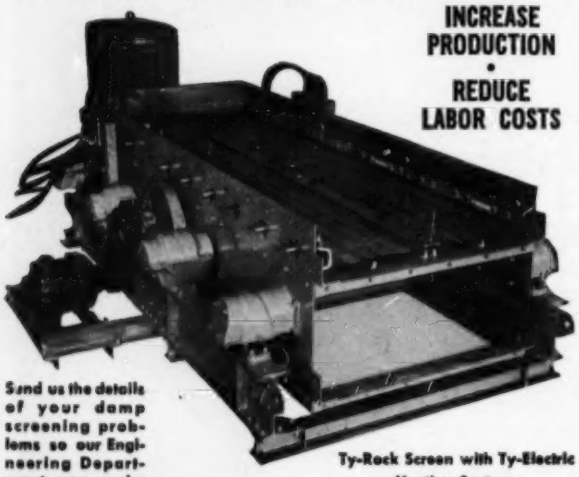

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# Personals

**Jack B. Graham,** formerly with the U.S. Geological Survey, Washington, D. C., has joined the staff of Leggette & Brashears, consulting groundwater geologists, New York. After receiving a Ph.D. degree in geology from the University of Iowa in 1942, Mr. Graham joined the USGS working on groundwater investigations chiefly in Wyoming and was in charge of groundwater work in Pennsylvania for about 9 years. In 1952, he was assigned to the Washington office of the USGS as chief, Water Utilization Section, Water Resources Div. In addition to membership in numerous scientific societies Mr. Graham is secretary of the Section of Geology and Geography of the American Assn. for the Advancement of Science and a member of the Subcommittee on Industrial Water Supply of the AIME.

**J. H. Pierce,** chairman of the board, Pierce Management Inc., Scranton, Pa., recently returned from a trip to Japan, Korea, Burma, and Brazil. **John Marshall,** president, has left to visit Burma, Greece, and Spain, and **William Lesser,** mechanical-electrical engineer, spent March in Greece.

**Albert P. Ruotsala** has resigned his position as exploration geologist with Bear Creek Mining Co. to finish work toward an M.S. degree. He is at present teaching at Macalaster College, St. Paul, and will teach through the summer session. Mr. Ruotsala, who expects to receive his degree in December, may be reached through the Dept. of Geology, University of Minnesota, Minneapolis.

**Roger Howell** is now project manager in Rangoon, Burma, for Pierce Management Inc., of Scranton, Pa. Mr. Howell, who was with Glen Alden Co., Wilkes-Barre, Pa., for 30 years, is supervising development of Burma's coal industry. The country has never had a solid fuel industry prior to this venture. Mr. Howell is also actively building an AIME chapter in Burma.

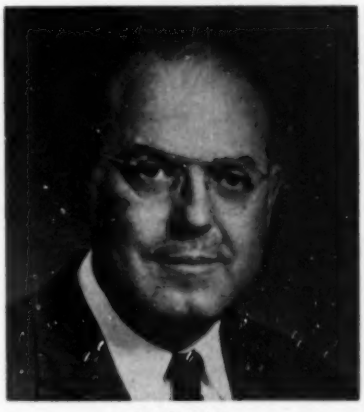
**Walter Rothenhoefer,** general manager of coal sales, Eastern Gas & Fuel Associates, Pittsburgh, has announced additions to the engineering staff of the sales organization. **C. H. Sawyer** has been named consulting engineer and will be in charge of technical services with particular attention to carbonization and gasification. **R. I. Bush** has been made combustion engineer. Both Mr. Sawyer and Mr. Bush, who have been associated with Eastern for several years, will continue to make their headquarters in Pittsburgh.

**Walter A. Smith** has accepted a position as general superintendent for San Luis Mining Co., Esqueda, Sonora, Mexico.

E. W. DOUGLASS

**E. W. Douglass** has resigned as research director, Potash Co. of America, Carlsbad, N. M. He has held this position for the past 8 years and was employed in a research capacity by the company 3 years prior to that. Before 1943, Mr. Douglass was employed in research and technical capacities by Ozark-Mahoning Co., Tulsa, Okla., in connection with salt cake, sulphuric acid, and other heavy chemical operations. After graduating from Iowa State College, he was employed by the Anglo-Chilean Consolidated Nitrate Corp. and later by the Latauro Nitrate Corp. in Chile. He worked there in the refrigeration, leaching and graining sections. Mr. Douglass now plans to do engineering consulting in the chemical and metallurgical fields. His address will be 1113 Tracy Place, Carlsbad, N. M.

**J. D. Turner** has been transferred from Denver to Washington, D. C., to become chief of the Mining Branch, U. S. Geological Survey. Former chief **H. I. Smith** has retired.



H. R. RICE

**H. R. Rice,** formerly editor of *Canadian Mining Journal,* is now professor and head, Dept. of Mining Engineering, Faculty of Applied Science & Engineering, University of Toronto.

**Paul Svendsen** has resigned as product engineer with the Mining Sales Dept. of Colorado Fuel & Iron Corp. to accept a position as research metallurgist with the Colorado School of Mines Research Foundation in Golden, Colo.

**Norman K. Flint,** professor, University of Pittsburgh, has been nominated president of the Pittsburgh Geological Society.

**Calvin O. Davies,** mining engineer, who was with Western Gypsum Co., Sigurd, Utah, is with Certain-Teed Products Corp., Blue Rapids, Kans.

**John F. Coulthard,** mining engineer, is with Kennecott Copper Corp., Nevada Mines Div., Ruth, Nev. He was with the Empire Zinc Div., New Jersey Zinc Co., Gilman, Colo.

**Frederick B. Hyder** is retiring as Principal Valuation Engineer, Court Defense Section, U.S. Bureau of Internal Revenue, Washington, D. C. Mr. Hyder will resume private practice in California.

**Tibor Boldizar** has been appointed head of Dept. II of Mining Machines, Technical University of Sopron, in Hungary.

**Gustav Egloff** will be awarded the 1954 Carl-Engler-Medaille, Germany's highest award in the field of mineral oil science. Mr. Egloff, who is director of research for Universal Oil Products Co., Des Plaines, Ill., will be the first scientist living outside Germany to receive the award. He will receive the medal in October during the annual congress of the German Institute of Petroleum and Coal. He will address the congress on *Chemistry in the Modern Oil Industry.* Following the congress, Mr. Egloff will make an intensive study of the latest advances in Germany's chemical fields. He also plans to give a series of lectures before West German universities and technical schools.

**Sheldon H. Penn,** who was with the Aero Service Corp., Philadelphia, is now a geologist with the National Lead Co. and is making his headquarters in Monticello, Utah.

**John D. Burgess,** graduate of Mackay School of Mines in 1938, and recently assistant superintendent, Kaiser Steel Corp.'s iron ore mine, Eagle Mountain, Calif., has been engaged by Cyprus Mines Corp. He will be assistant resident manager for its operations on the Island of Cyprus, and reports there early next fall. His previous experience has included service with Consolidated Coppermines Corp., American Smelting & Refining Co., and Ventures Ltd. in Canada. **Robert J. Hendricks** is resident director and manager of the property on Cyprus.

J. B. HAFFNER

**Foster L. Reed,** comptroller, Joy Mfg. Co., Pittsburgh, has been elected to membership in the Controllers Institute of America. Established in 1931, the institute is a nonprofit organization of controllers and finance officers from all lines of business, banking, manufacturing, utilities, transportation, etc. The total membership exceeds 4200.

**Frank A. Ayer,** international copper mining consultant, and **Walter H. Sammis,** president of Ohio Edison Co., are the 1954 winners of the Egleston Medal, Columbia University's highest award "for distinguished engineering achievement." Both recipients are graduates of the school. Mr. Ayer recently was associated with the Copper Range Co. and Phelps Dodge Corp. He formerly served with two copper mining companies in South Africa. Mr. Sammis heads the Pennsylvania Power Co. as well as Ohio Edison Co. He is president of the Edison Institute for the 1953 to 1954 term.

**Hugh H. Bein** has been named manager of the Del Monte sand plant of the Del Monte Properties Co., Pebble Beach, Calif. Mr. Bein attended Colorado School of Mines and graduated from the University of Wyoming. He spent 3 years in the Philippines, worked a year and a half in Colorado with the Atomic Energy Commission, and most recently was with American Cyanamid Co., which is operating a research laboratory for the AEC, with headquarters in Winchester, Mass.

**Paul H. Cardwell,** laboratory director of Dowell Inc., Tulsa, Okla., has been assigned to the staff of **John J. Grebe,** Midland, Mich. Mr. Grebe is vice president of Dowell Inc. and research consultant of The Dow Chemical Co. In his new assignment, Mr. Cardwell will represent Dowell with the 16 Dow research laboratories at Midland, and also with those research groups located at the Dr. W. R. Veazey research center at Freeport, Texas.

**J. B. Haffner** (AIME Director 1948 to 1950) has been elected president of Bunker Hill & Sullivan Mining & Concentrating Co., Kellog, Idaho. He succeeds **Stanly A. Easton** (AIME Director 1919 to 1921, W. L. Saunders Medalist 1949) who has retired after 20 years as president to take the newly established position of chairman of the board of directors. **P. C. Feddersen,** who was general smelter superintendent, succeeds Mr. Haffner as general manager of the firm. **Harold E. Lee,** superintendent of metallurgy and research, is now general smelter superintendent.

**John D. Bradley,** executive vice president, Bradley Mining Co., San Francisco, has been elected executive vice president, Bunker Hill & Sullivan Mining & Concentrating Co.

**Robert W. Lawson,** Salt Lake City manager for Ingersoll-Rand Co., was recently the subject of a "Business Portrait" in *The Salt Lake City Tribune.* A great deal of the article was devoted to Mr. Lawson's experiences in Asia where he was with the Office of Strategic Services during World War II.

**J. M. Hoff** has been elected president of Willow Valley Mines Inc., San Francisco. This is the only company now operating on gold in Nevada City, Calif. Ten men are employed, and mill heads in their 100 ton flotation have been high enough for continued operation.

**Clayton E. Warren** has accepted a position as production and bonus engineer with Dominion Wabana Ore Ltd., Bell Island, Newfoundland.

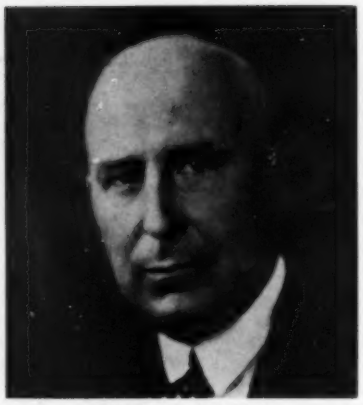
**Anatol Glas** is now with the research dept., American Smelting & Refining Co., South Plainfield, N. J.

**H. Loevenstein,** administrative engineer, Harvey Machine Co., Torrance, Calif., may now be reached through Harvey Aluminum Co., at Salem, Ore.

**Wilford C. Craven,** who was with Cia. Aramayo de Mines en Bolivia, in La Paz, is now a metallurgical engineer and shift boss engineer with International Nickel Co. of Canada, Copper Cliff, Ont.

**Lloyd W. Ingles** is superintendent of Colorado Fuel & Iron Corp.'s new Allen mine at Weston, Colo. Mr. Ingles has been superintendent of CF&I's Frederick mine since August 1951, following 2 years as superintendent of CF&I's Kebler and Pictou mines. He also served as superintendent of CF&I's Crested Butte for 3 years. Mr. Ingles joined the company as assistant engineer with the CF&I Mining Dept. in 1920.

**Francis T. Heuring** is employed as a geophysicist by the U.S. Hydrographic Office, Suitland, Md.



STANLY A. EASTON

**M. A. Matthews,** president of Templeton-Matthews Corp., Terre Haute, Ind., announced that **William C. Ehinger** is now with that organization as chief mechanical engineer. Templeton-Matthews Corp. provides technical services to the coal mining industry, as consultants, designers, and builders of preparation plants.

**Kjell Amdahl,** formerly with A/S Norsk Bergverk, Oslo, Norway, is with Boliden Gruv-Aktie-Bolag, Boliden, Sweden.

**A. Joseph Yaeger, Jr.,** mining engineer with American Smelting & Refining Co., El Paso, Texas, is now with Asarco's Mexican Mining Dept. in Mexico City.

**C. H. Murphey** is executive director of the New Mexico Mining Assn. with offices in the Laughlin Bldg., Santa Fe, N. M.

**Donald Carnes** is now senior geologist, Tennessee Coal & Iron Div., U. S. Steel Co., Bessemer, Ala.

**George Eilertson,** who was concentrating plant superintendent for Jones & Laughlin Steel Corp., Minnesota Ore Div., Virginia, Minn., has been named chief chemist, succeeding **Frank Kishel** who retired recently. **Russell Abercrombie,** a beneficiation engineer, has been named concentrating plant superintendent to succeed Mr. Eilertson.

**Victor Hollister,** geologist for American Smelting & Refining Co.'s Northwest mining div., Wallace, Idaho, has been transferred to the staff of Northern Peru Mining & Smelting Co., the wholly owned Asarco subsidiary, which operates the Quiruvilca underground copper mine located in the Andes at an elevation of 12,000 ft.

**Orson A. Rockwell,** formerly vice president of Calumet & Hecla Inc., has been elected a vice president and director of Eagle-Picher Co. Mr. Rockwell will be general manager of the mining & smelting div. with headquarters at Miami, Okla.

CARROLL L. WILSON

**Carroll L. Wilson** has been shifted from the presidency of Climax Uranium Co. to devote full time to his post of director of industrial development of Climax Molybdenum Co. He will retain his connection with Climax Uranium as a member of its board of directors. **John H. White, Jr.,** has been elected to succeed Mr. Wilson as president of Climax Uranium Co., and the presidency has been made a full-time post with headquarters in Grand Junction, Colo. Mr. White is president of Climax Molybdenum Co. (of Pennsylvania), with its plant in Langeloth, Pa.

**Lucien Eaton, Jr.,** formerly engineer at the Hibbing, Minn., and Chicago offices of Western-Knapp Engineering Co., is now with Utah Construction Co., Jefferson City, Tenn.

**John H. Schissler, Jr.,** who was chief engineer, The Fresnillo Co., Fresnillo, Mexico, is now with Reynolds Mining Corp., Miragoane, Haiti.

**Robert E. Dye** has retired as general manager of Dome Mines Ltd., South Porcupine, Ont., but will continue with the company as a consultant. **Charles P. Girdwood,** who was general superintendent, is now general manager of Dome. Mr. Girdwood joined the company in 1939 as assistant engineer.

**E. W. Felegy,** mining engineer with the U. S. Bureau of Mines, who was in Duluth, is now stationed in San Bernardino, Calif.

**R. B. Brackin** is leaving his position as assistant mill superintendent, American Zinc Co. of Tennessee, Mascot, Tenn., to be in charge of Kaiser Steel Corp.'s new 11,000-tpd iron ore treatment plant at Eagle Mountain, Calif.

**Grover J. Holt,** general manager, Cleveland-Cliffs Iron Co., has announced that **Emert W. Lindroos,** formerly district metallurgist at the Republic mine, is assistant superintendent of the Humboldt mine, in Michigan.

**Robert A. Stauffer** and **Kenneth G. Donald** have been elected to the board of directors of National Research Corp., Cambridge, Mass. Mr. Stauffer has been vice president and director of research at National Research Corp. since 1949. He is also vice president and a director of Vacuum Metals Corp., jointly owned by Crucible Steel Co. of America and National Research Corp. Mr. Donald, who has been vice president and treasurer of National Research Corp. since February 1953, is also assistant treasurer and a director of Vacuum Metals Corp.

**Keith S. Shiress** has accepted the appointment of power plant maintenance engineer to the Rhokana Corp. Ltd. in Northern Rhodesia.

**R. A. Matuszeski** has joined the engineering staff of American Car & Foundry Co., Albuquerque, N. M. He was supervisor of the metallurgical dept. at the Cincinnati feed materials center operated by the National Lead Co. for the Atomic Energy Commission.

**Jay A. Poll** is assistant general plant superintendent, Nickel Processing Corp., Nicaro, Oriente Province, Cuba. He was superintendent of the Humboldt mine operated by Cleveland-Cliffs Iron Co., Ishpeming, Mich.

ROBERT T. CHAPMAN

**Robert T. Chapman,** recently mining consultant for Union Carbide & Carbon Corp., New York, has joined the Potash Co. of America, at Carlsbad, N. M., as assistant resident manager.

**Robert C. Landstrom,** vice president and secretary of Miller & Co., Chicago, is serving as section chairman in the trades and industry div. of the 1954 Cancer Society fund campaign. Mr. Landstrom will direct the activities of about 1500 volunteers who will seek funds from over 7225 firms in the area.

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# Obituaries

Appreciation of
**Donald C. Brown**
by A. D. Sproat

Donald Charles Brown (Member 1901) died Jan. 19, 1954 at the age of 89 in San Luis Potosi, Mexico.

Mr. Brown first came to Mexico in 1886 in the employ of Robert S. Towne of the Kansas City Smelting & Refining Co. to buy ore for that company's El Paso smelter. Mr. Brown was a graduate of Marietta College, Ohio, in 1884.

At the time of his death Mr. Brown was president of the Fresnillo Co. with which company he had been associated for many years.

He is survived by his widow, Alice Eells Brown. He was a Legion of Honor Member of AIME.

**Francis V. Dempsey** (Member 1936) died in San Francisco, Jan. 20, 1954. He had been ill for several weeks. Mr. Dempsey had just finished some consulting work for the Idaho-Maryland mine, Grass Valley, Calif. He was born in Vallejo, Calif., in 1901 and was educated at St. Mary's College, Moraga, Calif. His great-grandfather was General Vallejo, a prominent California military and governmental leader. Mr. Dempsey was for many years superintendent of the Consolidated Chollar Gould & Savage Mining Co., Gold Hill, Nev., and also at various times superintendent for the Duvall Co., Ogden, Utah, and the Beebe Gold Mining Co., Georgetown, Calif.

Appreciation of
**Christian A. Anderson**
by Arthur C. Brinker and
Irene K. Sharp

Christian A. Anderson (Member 1932) passed away very suddenly Dec. 1, 1953 in Bridgewater, Maine, at the station while waiting for a train to return him to New York. Born in Copenhagen, Denmark, he started his education in his native Denmark, going on to Germany, and continuing his pursuit of knowledge in the mining field at the University of Washington here in the U. S. Becoming a citizen almost immediately upon his arrival in the U. S., Andy enlisted in the Army in World War I, upon our entry into the war, rising to the rank of sergeant by the time he was discharged. The American Legion therefore honored Mr. Anderson with the traditional military ceremonies.

During his lifetime, he was connected with the Titanium Alloys Mfg. Co., Australia, was mill superintendent for a British mining company in Korea, worked on Kuiu Island, Alaska, was manager of Tanapaca tin mines for International Mining Co., Bolivia, and superintendent for Northern Peru Mining & Smelting Co. He also did personal prospecting in Central America, explored diamond concessions in Venezuela for Harry Winston, and a copper concession in Haiti for East India Co. At the time of his death he was consulting engineer for E. S. Nossen Laboratories working on manganese bearing rock.

His varied and interesting professional career took him to all parts of the globe where he made many friends who all felt, as we did here in the Institute, that it was a privilege and delight to know "Andy," as he was so affectionately called by all who knew him. His always cheery "Hello," his optimistic philosophy of life, and his ever-thoughtfulness of others will be greatly missed by all of us.

An Appreciation of
**Lloyd Malcolm Kniffin**
By E. W. Pehrson

Lloyd Malcolm Kniffin passed away on February 16 in Garfield Hospital, Washington, D. C., after a brief illness. He was buried on February 19 at Fort Lincoln Cemetery in the nation's capital. By his death his family has lost a devoted husband and father, his associates a wise counselor and a warm friend, and the profession a conscientious and successful engineer with broad experience and interests.

Mr. Kniffin was born on Apr. 5, 1884, at Lew Beach, Sullivan County, N. Y. His early education was obtained in the public schools of Paterson, N. J., whither his family had moved when Lloyd was a small boy. He received the degree of E.M. from Columbia University in 1906. His first assignment after graduation was with the Mines Co. of America in Chihuahua, Mexico, where he was first cyanide plant boss, then superintendent at Dolores; mill superintendent at Lluvia de Oro; and mine superintendent at Batopilas. In March 1911, President Taft recalled American citizens living in Mexico. Mr. Kniffin then joined the U. S. Smelting Refining & Mining Co., with which organization he remained until 1936. During this period he served in numerous capacities, including superintendent of the electrolytic lead refinery at East Chicago, supervisor of production and transportation at Pachuca, Mexico, organizer and operator of the company's central research laboratory in Boston, and manager of iron and copper mines in New Mexico.

When the latter operation was discontinued, Mr. Kniffin turned his talents to oil development and production, serving as manager of the Rosita Oil Co. in Texas from 1936 to 1941. During this same period he was consulting engineer to the Dept. of Economy of the Mexican Government on iron and steel investigations.

During World War II Mr. Kniffin was employed in Washington with the Reconstruction Finance Corp., Defense Plant Corp., and War Assets Administration. In March 1948 he joined the Valencia Iron & Chemical Corp., pig iron manufacturers at Rusk, Texas, but in 1949 he again entered Government service with the Bureau of Mines. At the time of his death he was engaged in analytical studies of the mineral economy of European countries in the Bureau's Foreign Minerals Region.

In 1908 Mr. Kniffin married Miss Mary Fairhurst, a native of New Zealand, whom he met during school days in Paterson, N. J. Mrs. Kniffin, three children, and eight grandchildren survive him. A daughter, Mrs. Audrey von Plonski, is employed in the Latin American Affairs Div. of the Dept. of State. Two sons are practicing industrial engineers; Lloyd F. resides in Stratford, Conn., and Robert F. in Bedford, Ohio. Mrs. Kniffin plans to continue living in

## Necrology

| Date Elected | Name | Date of Death |
|---|---|---|
| 1941 | Francis H. Brownell | Mar. 8, 1954 |
| 1937 | Benjamin Eggers | March 1954 |
| 1902 | Fernando C. Fuchs | Feb. 21, 1954 |
| 1944 | Willard S. Girvin | Unknown |
| 1915 | Oliver Hall | Feb. 15, 1954 |
| 1945 | James Hannigan | Unknown |
| 1936 | Ames B. Hettrick | Dec. 27, 1953 |
| 1940 | K. M. Leute | Mar. 24, 1954 |
| 1940 | Orville R. Lyons | Feb. 2, 1954 |
| 1950 | F. R. McNamara | January 1954 |
| 1949 | Albert Wood Morris | Apr. 1, 1954 |
| 1938 | A. L. Schneider | Feb. 23, 1954 |
| 1912 | Henry L. Slosson, Jr. | Unknown |
| 1943 | Jacques Van Tijn | Mar. 13, 1954 |
| 1952 | Arthur Waldman | Mar. 10, 1954 |


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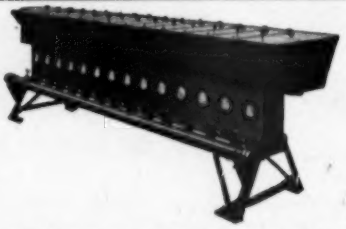

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Lloyd M. Kniffin was a Member of the AIME, the American Foundrymen's Society, the Metropolitan Methodist Church of Washington, and he was active in Columbia University alumni activities in the Washington area.

**Neil E. Salsich** (Member 1944) died suddenly Feb. 2, 1954 in Bethlehem, Pa., where he was to have met with Bethlehem Steel officials during the day. He had been since 1931 vice president and director of The Jeffrey Mfg. Co., Columbus, Ohio. Born in Hartland, Wis., in 1883, he attended Beloit College in Wisconsin. In 1903 Mr. Salsich became associated with the Pennsylvania Steel Co., Steelton, Pa., which was later absorbed by the Bethlehem Steel Co. He was with these companies for 28 years in various capacities. Twenty U. S. patents issued to him are now owned by Bethlehem Steel Co. Among the many organizations Mr. Salsich belonged to were the Jeffrey Foremen's Club, Jeffrey 20-Year Service Club, Old Timers Club, American Iron & Steel Institute, and the Illinois Mining Institute.

**Joseph Schlickau** (Member 1953) died Nov. 9, 1953 of a heart attack. He was a consulting mining engineer who worked in many parts of the world. Mr. Schlickau was born in Neheim, Westphalia, Germany, in 1902 and studied at the Mining Academy in Clausthal, the University of Munich, and the University of Berlin. In 1929 he came to the U.S. as an exchange mining engineer, then worked as a consulting engineer in Spain. From 1936 to 1938 he was employed by the AEG Electric Co. in London. From 1939 to 1944 he was chief mining engineer for the German steel and coal combine, Gutehoffnungshütte, first in Brazil, later in Romania where he was in charge of company coal mines and oil wells. From 1944 to 1948 he was a forced laborer in a Russian prison camp. Following release he returned to GHH and introduced new mining systems in Great Britain, France, Belgium, Netherlands, and the U.S. Mr. Schlickau immigrated to the U.S. about two years ago and had taken out his first papers. He had been living in Pikeville, Ky.

**Alfred W. G. Wilson** (Member 1906) died in Ottawa, Ont., Jan. 9, 1954. He was for many years chief of the Mineral Resources Div., Federal Dept. of Mines, Ottawa, and at the time of his retirement in 1941, chief technical consultant. Mr. Wilson was born in Cobourg, Ont., in 1873 and received his B.A. from the University of Toronto in 1893. He received his M.A. in 1899 and his Ph.D. in 1901 from Harvard University. After a year of post-doctorate study at Columbia School of Mines, he went to McGill University where he was a lecturer until 1904. From 1902 to 1909, Mr. Wilson was engaged in consulting work as mining geologist and physiographic engineer and led survey and prospecting expeditions in various parts of Canada. Much of this work was undertaken for the Canadian Pacific Railway.

During World War I he was technical adviser to the Shell Committee, the War Trade Board, and the Tariff Board. He invented a process for making shrapnel and in 1916 organized Wilson Munitions Ltd. which turned out some $500,000 worth of shrapnel. During World War II Mr. Wilson acted as special consultant on strategic minerals and chemicals to the National Defense, Finance, and Trade and Commerce Depts. He was chairman of the Defense Dept.'s Chemical Supplies Committee. He was the author of several books on mining and related subjects and of numerous technical papers. Mr. Wilson was a Life Member of CIM, a Life Fellow of the Geological Society of America, and a Life Member of the IMM, London.

**Harold S. Worcester** (Member 1945) died Feb. 1, 1954 as the result of a heart attack which occurred in Denver where he was attending the National Western Mining Conference. He had just a few days before been elected president of the Colorado Mining Assn. Mr. Worcester maintained headquarters as a mining consultant at Montrose, Colo. He was also owner of Worcester Mines, a uranium development at Atkinston Mesa, near Uravan, Colo. Mr. Worcester was born in Arvada, Colo., in 1891. He gained his first mining experience working in various mines and operations in the Cripple Creek district. He graduated from the University of Colorado in 1916 with a B.S. in mechanical engineering and became a sales engineer for Sullivan Machinery Co. Among the other companies Mr. Worcester later worked for were the Rico Argentine Mining Co., Rico, Colo., where he was general superintendent; Fremont Gover Co., Amador City, Calif., where he was manager. Mr. Worcester was for many years manager of the Smuggler Union mine at Telluride, Colo. He was superintendent from 1927 to 1929 and when the mine closed in 1929, he wrote and published a history of this famous mine. When it reopened in 1940, Mr. Worcester was manager of the new operating company, Telluride Mining & Milling Co. and remained with the firm until about 5 years ago when he resigned to enter business for himself.

**Calvert C. Wright** (Member 1944) died Feb. 1, 1954 of a heart attack while he was reading the commentary for a film entitled *The Story of Anthracite*, being made for the anthracite industry. He was professor and chief of the div. of fuel technology at Pennsylvania State University, State College, Pa. Mr. Wright was born in 1905 in Southport, England, and received his B.S. degree in 1927 and his Ph.D. in 1931 in chemical engineering from the University of Washington, Seattle. He first went to Pennsylvania University in 1932 as the recipient of a National Research Council Fellowship in chemistry to study the hydrogenation of coal. He held the following positions in fuel technology: research assistant 1934 to 1936; associate professor 1936 to 1942; professor 1942 to 1945; and division chief since 1945. Although still a young man, he was internationally known for his research on the origin, constitution, processing, gasification, carbonization, and utilization of coal. He was the author or coauthor of 75 publications and held several patents pertaining to fuels. Mr. Wright was Chairman of the AIME Coal Div. Gasification Subcommittee.

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*Grand Junction*—Brewer, Quenton L. (M)
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# Coming Events

**May 9-11, Southeastern Retail Coal Assn.,** Annual Convention, Atlanta-Biltmore Hotel, Atlanta, Ga.

**May 14-15, AIME, Central Appalachian Section,** spring meeting, Hotel Morgan, Morgantown, W. Va.

**May 15, AIME Southeast Section,** Social Meeting, Birmingham.

**May 17-19, Indiana Coal Merchants Assn.,** Annual Meeting, French Lick, Ind.

**May 20, AIME Utah Section,** Student Section Meeting, dinner and program, Geology Bldg., University of Utah, Salt Lake City.

**May 24-25, Ohio Coal Conference,** Annual Convention, Neill House, Columbus, Ohio.

**May 24-27, Symposium on Instrumentation Industrial Hygiene,** University of Michigan, Ann Arbor.

**May 26-28, Southern Appalachian Industrial Exhibit,** Bluefield, W. Va.

**May 27, Central Pennsylvania Coal Producers Assn.,** Penn-Alto Hotel, Altoona, Pa.

**June 4, Big Sandy-Elkhorn Coal Operators Assn.,** Annual Meeting, Lexington, Ky.

**June 12, AIME Colorado Minerals Beneficiation Subsection,** Annual Meeting, Climax, Colo.

**June 14-18, American Society for Engineering Education** Annual Meeting, University of Illinois, Urbana, Ill.

**June 14-18, Second U. S. Congress of Theo. & Appld. Mech. Meeting,** University of Michigan, Ann Arbor.

**June 20-24, American Society of Mechanical Engineers,** Wm. Penn Hotel, Pittsburgh.

**June 20-25, American Institute of Chemical Engineers,** nuclear energy meeting, University of Michigan, Ann Arbor, Mich.

**June 23-26, American Coal Sales Assn.,** Annual Convention, Colorado Springs, Colo.

**June 25-26, 1954 Pacific Coast Regional Conference** on Clays and Clay Technology, University of California, Berkeley, Calif.

**July 25-Aug. 10, World Power Conference,** Sectional Meeting, Rio de Janeiro, Brazil.

**Aug. 2-12, Pan American Federation of Engineering Societies (UPADI),** 3rd Convention, Sao Paulo, Brazil.

**Sept. 8-10, American Society of Mech. Engrs.,** Fall Meeting, Schroeder Hotel, Milwaukee.

**Sept. 10, AIME Lehigh Valley,** Annual Inspection Trip, Ingersoll-Rand Co., Phillipsburg, N. J.

**Sept. 20-24, American Mining Congress,** Civic Auditorium, San Francisco.

**Sept. 23-24, Central Pennsylvania Coal Producers Assn.,** Annual Meeting, Bedford Springs Hotel, Bedford, Pa.

**Sept. 24, AIME, Minerals Beneficiation Div.,** Fall Meeting, Fairmont Hotel, San Francisco.

**Sept. 30, AIME Utah Section,** Stag: cocktails, dinner, smoker, 7:00 pm Newhouse Hotel.

**Oct. 5-9, AIME Industrial Minerals Div., Fall Meeting,** Whiteface Inn, Lake Placid, N. Y.

**Oct. 27-29, Clay Mineral Technology, Third National Clay Minerals Conference,** Rice Institute, Houston. Those interested in presenting papers should announce their intentions to A. F. Frederickson, Washington University, St. Louis, on or before July 15.

**Oct. 28-30, AIME, ASME Fuels Conference,** William Penn Hotel, Pittsburgh.

**Oct. 29-30, AIME, Industrial Minerals Div.,** Rocky Mountain Region Industrial Minerals Conference, Salt Lake City. Registration Oct. 28.

**Nov. 12, Illinois Mining Institute,** Hotel Abraham Lincoln, Springfield, Ill.

**Nov. 13-18, ASME, 75th Anniversary Meeting, Congress & Hilton, Chicago.**

**Nov. 18, AIME, Utah Local Section,** joint meeting with Intermountain Assn. of Petroleum Geologists, 8:00 pm, Newhouse Hotel, Salt Lake City.

**Nov. 18, American Mining Congress, Coal Div.,** Wm. Penn Hotel, Pittsburgh.

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